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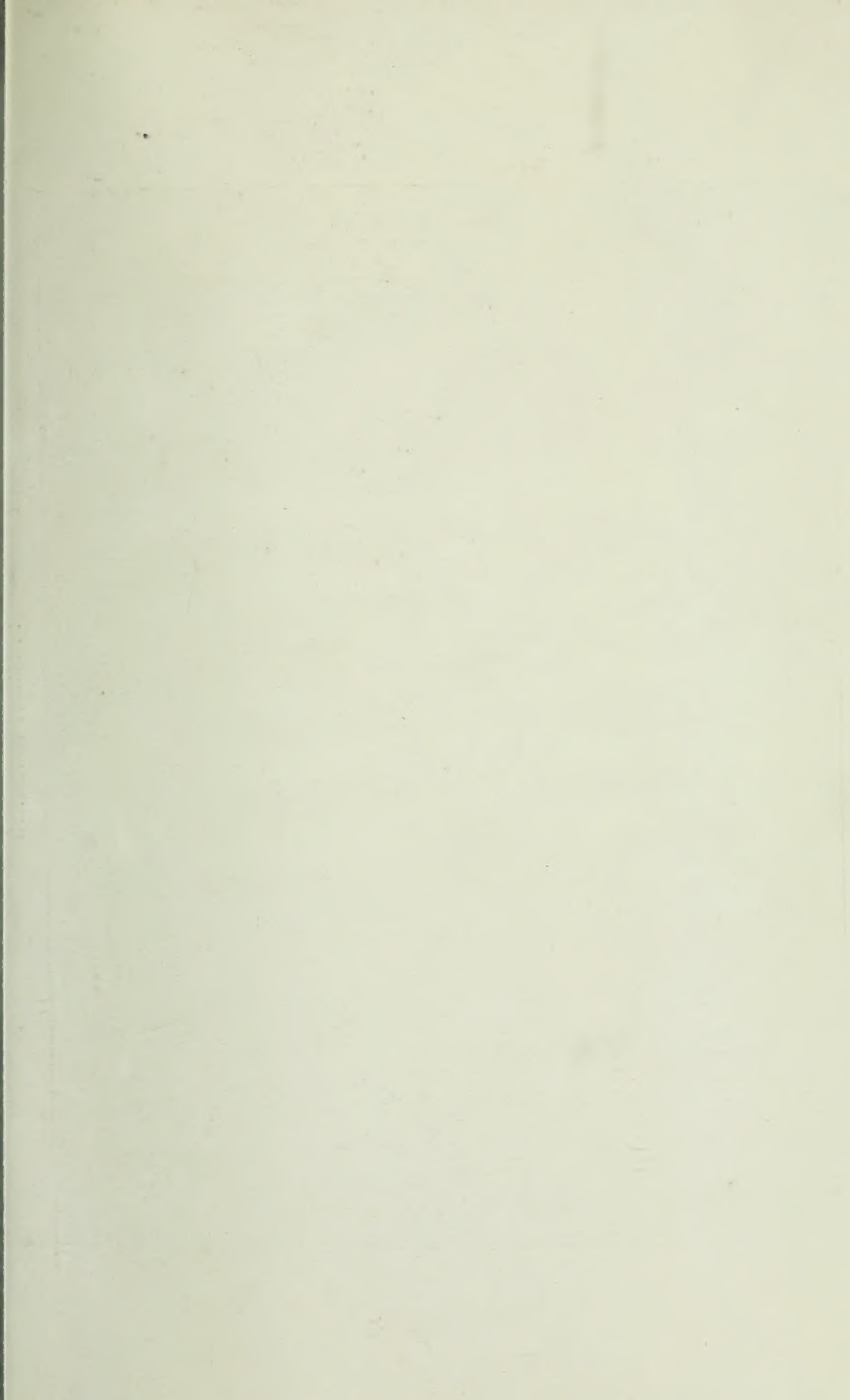
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GLASGOW MEETING

THE JOURNAL

OF THE

INSTITUTE OF METALS

VOLUME IV

EDITED BY

G. SHAW SCOTT, M.Sc.

SECRETARY

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THE INSTITUTE OF METALS

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THE INSTITUTE OF METALS

SECTION I.

MINUTES OF PROCEEDINGS.

MAY LECTURE.

AT a GENERAL MEETING of the Institute held at the Institution of Mechanical Engineers, Storey's Gate, Westminster, S.W., on Tuesday, May 24, 1910—Sir GERARD MUNTZ, Bart., President, in the Chair—there was delivered the first May Lecture by Professor W. Gowland, Assoc.R.S.M., F.R.S.

The MINUTES of the Annual General Meeting, held in London on January 18 and 19, 1910, were taken as read, and were signed by the Chairman.

PROFESSOR GOWLAND then delivered his lecture on the subject of "The Art of Working Metals in Japan," a full report of which will be found on pages 4-41.

VOTE OF THANKS TO PROFESSOR GOWLAND.

The PRESIDENT proposed, and Professor TURNER seconded, and it was carried unanimously, that a hearty vote of thanks be given to Professor Gowland for his lecture.

ELECTION OF MEMBERS.

The SECRETARY read the following list of names of candidates who had been duly elected members of the Institute—

Election of Members

NAME.	ADDRESS.	QUALIFICATION.	PROPOSERS.
Allan, Andrew, Jun.	486 Greenwich St., New York City, U.S.A.	Manufacturer of Bearing Metals	Palmer H. Langdon. H. C. H. Carpenter. G. A. Boeddicker.
Bassett, William H.	Waterbury, Con- necticut, U.S.A.	Metallurgist, The American Brass Co.	Henry M. Howe. H. O. Hofman. G. A. Boeddicker.
Beilby, George Thomas, LL.D., F.R.S.	11 University Gar- dens, Glasgow	Metallurgist	H. C. H. Carpenter. C. H. Desch. Sir W. H. White.
Brain, Henry Richard (<i>Student</i>)	67 Park Street, S.E.	Founder	C. F. Gaywood. F. G. Penny. J. J. Edwards.
Brook, George Ber- nard	Cravenhurst, Ful- wood, Sheffield	Analytical Chemist	R. J. Brown. Cecil H. Wilson. W. R. Barclay.
Campion, Alfred	Glasgow and West of Scotland Techni- cal College, Glasgow	Metallurgist	C. H. Desch. F. W. Harbord. E. F. Law.
Corin, Alfred An- toine François	Rue de l'Hotel Communal, Hol- logne aux Pierres, Belgium	Metallurgical En- gineer	E. Ristori. H. C. H. Carpenter. R. Kaye Gray.
Gregory, Sewell Harding	36 Wetherby Man- sions, Earl's Court, S.W.	Crucible Manu- facturer	H. B. Weeks. W. H. Child. T. A. Bayliss.
Hughes, George	Lancashire and Yorkshire Railway Works, Horwich	Engineer	Sir W. H. White. James Denny. C. A. Edwards.
Mason, Frank	42 Birkendale Rd., Upperthorpe, Sheffield	Manager, Electro- plating Dept., Mappin & Webb, Ltd.	R. J. Brown. W. R. Barclay. P. Longmuir.
Mills, Frank	6 Bank Street, Man- chester	Lancashire Mana- ger, Cammell, Laird, & Co., Ltd.	W. H. Child. R. Wright. T. A. Bayliss.
Morehead, Charles	2 Tynemouth Ter., Tynemouth	Foundry Manager	W. B. Parker. P. Longmuir. F. H. Hurren.
Murray, Myle- Thornton, M.Sc.	Transvaal Univer- sity Coll., Johan- nesburg	Lecturer and De- monstrator in Metallurgy and Assaying	A. K. Huntington. G. H. Stanley. T. Turner. O. F. Hudson.
Tabor, Howard James (<i>Student</i>)	17 Sebert Road, Forest Gate, E.	Assistant, Assay Office, Royal Mint	C. O. Bannister. W. N. Stanley. H. J. Humphries.
Walker, Herbert Carr	48 St. Michael's Rd., Headingley, Leeds	Founder of Copper and White Metal Alloys	G. Gummer. R. J. Brown. D. H. Farley.
Walkinton, Harry William	5 Eccles St., Win- cobank, Sheffield	Engineer	H. C. H. Carpenter. R. Kaye Gray. E. Ristori.
Westwood, Arthur	Assay Office, Bir- mingham	Assayer	Sir H. Wiggan, Bt. G. A. Boeddicker. T. Turner.

VOTES OF THANKS.

The PRESIDENT moved, and it was carried unanimously, that a vote of thanks be accorded to the Institution of Mechanical Engineers for their courtesy in allowing the use of their hall and rooms for the purpose of the lecture.

Mr. RISTORI moved, and it was carried unanimously, that a vote of thanks be passed to the scrutineers, Messrs. Arthur Johnson and W. Morton Johnson, for their services in connection with the ballot.

The proceedings then terminated.

THE ART OF WORKING METALS IN JAPAN.

BY PROF. WILLIAM GOWLAND, ASSOC.R.S.M., F.R.S. (*Vice-President*),
EMERITUS PROFESSOR OF METALLURGY AT THE ROYAL SCHOOL OF MINES.

THE subject which I have the honour and privilege to bring before you in the present lecture, "The Art of Working Metals in Japan," or rather I should say in Old Japan, is one which you will agree with me is of unusual interest. To the metallurgist and craftsman it presents unique modes of dealing with metals, of extracting and purifying them, and of adapting them by means of simple and often rude appliances and processes to both practical and ornamental uses. The metals I propose to deal with are gold, silver, and copper. Now these metals, together with iron and tin, are the only substances recognised as metals proper by early Chinese and Japanese writers. They are designated collectively by a special term—*Go-Kin*, which means the five metals; and they were supposed to have some mysterious relations with the five colours and also with the five planets. They were believed, according to Chinese philosophy, to have originated through the action of the sun and the masculine and feminine principles of Nature, and not to be simple bodies or elements, but to be capable, under certain conditions and influences, of being transmuted one into another.

Gold.—The first metal to which I shall ask your attention to-night is gold. It is called by native writers, both Japanese and Chinese, the king of the five metals. "because," they say, "it never rusts, and can be melted many times without appreciable loss of weight." Then, following the teachings of the old Chinese philosophers, it was believed that under special conditions other metals could be converted into gold, but this transmutation could not be effected in a laboratory, as a space of not less than two hundred years was required for its completion, even under the favourable influences of celestial

agencies. So that probably in consequence of that belief in the all-important influence of time, the occult science of Hermes, Albertus Magnus, and other Western alchemists, does not appear to have been practised in Japan; and much as the acquisition of gold was sought after, no records of any attempts to transmute a baser into the more noble metal have been handed down by tradition.

The source of gold in Japan, as in all countries in early times, was the sand of rivers, from which the metal was obtained by a series of simple washing processes, which were conducted with much skill. Later on mineral veins seem to have been discovered, in which the gold was embedded in quartz; then it was necessary that the quartz should be ground, and when it was ground the simple and old methods of washing were followed for the purpose of extracting the gold.

In Fig. 1, which is taken from an old Japanese manuscript, is depicted the process of extracting gold from quartz. The rock was first broken roughly by means of hammers until it could be ground to a pulp with water in a mill which resembles a flour-mill. The pulp after dilution with water was vanned and then washed with more water on inclined troughs, on the bottom of which long sheets of cotton cloths were laid. The result of the water and powdered ore passing over these cloths was this: the earthy matter was washed away and the gold adhered to the rough surface of the cotton cloths. These cloths were taken off after a certain time; they were washed in water and the gold was recovered. I may say, with regard to gold washing in Japan, that even until quite recent times the washing was so very skilfully carried on that the washers could work a river sand with a profit when we with our modern appliances were unable to make it pay. The old gold washers are said not to have received any wages, but sufficient gold dust adhered to their garments, and it is naïvely added that sometimes even a nugget became accidentally attached, and that was sufficient to recompense them for their labours.

Now with regard to the abundance of the metal, you find very glowing accounts by the old voyagers of the richness of Japan in gold. These accounts are based entirely on a misconception. These voyagers when they visited Japan saw

temples and buildings ornamented with what they thought were gold plates and ornaments, but in reality they were only copper with a coating of gold. That gold was not so abundant in Japan, the Sumptuary Laws recorded in ancient documents prove that it was always a precious metal and to be used sparingly; thus in the ninth century by one of these laws all officials below the sixth rank were forbidden to wear any gold or silver excepting on their armour, their swords, or their official robes. The effect of that law and similar subsequent laws survived up to our own times, so that the gold jewellery of a Japanese lady when I first arrived in Japan consisted

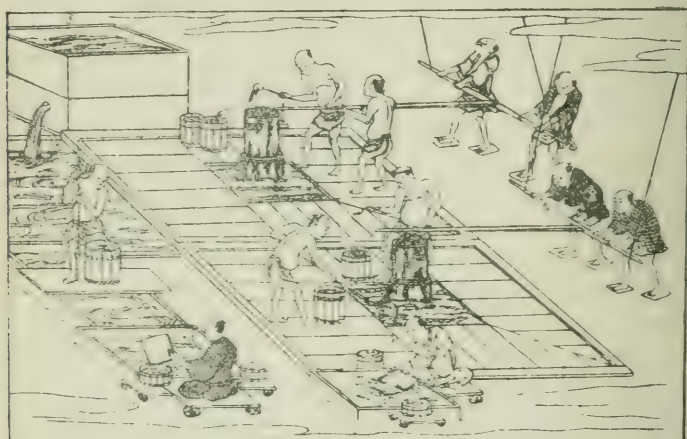


FIG. 1.—Grinding and Washing Gold Ore.

merely of a simple hairpin, and of a gentleman of the mounts of his sword, pipe, and tobacco pouch. But since then, that is, during the last thirty-eight years, this simplicity has come to an untimely end, and both sexes now bedeck themselves after the manner of the West.

Among the earliest examples existing of the use of gold are the objects shown in Fig. 2. which were taken from ancient burial mounds, also fragments of a tiara and of the ornamental bands which adorned the dress of an old chieftain who was interred in one of the mounds. The latter are constructed of thin sheets of copper thickly coated with gold.

The horse-bits shown in Fig. 2 are furnished with check pieces of iron, decorated with copper coated with gold.

With the introduction and establishment of Buddhism in

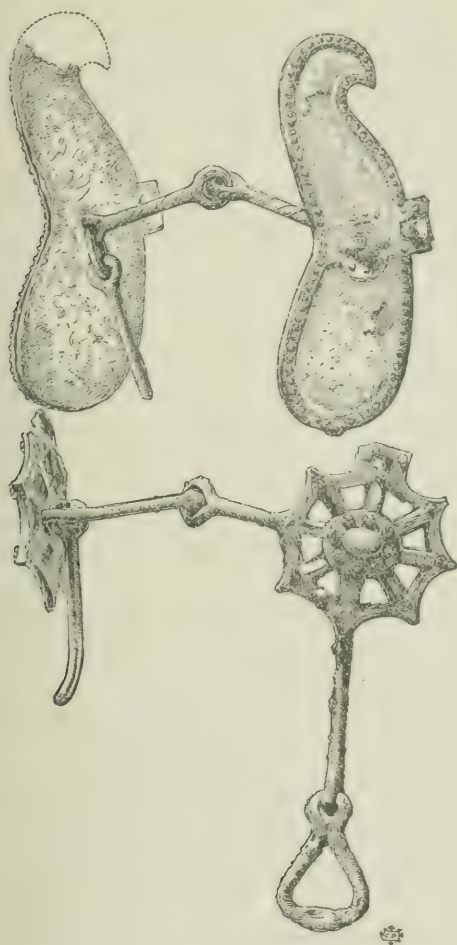


FIG. 2.—Horse-bits from a Dolmen at Rokuya (Tamba).

the sixth and seventh centuries, gold comes into use on a more extensive scale, but even now very rarely were articles made of solid gold, its chief application being for the gilding of bronze and wooden images of Buddhist divinities, of copper

vessels for ceremonial and ornamental purposes, and of copper plaques for the decoration of shrines.

Considerable quantities of gold were needed for these purposes, as the leaves of metal employed were of much greater thickness than those now used in Europe.

For the gilding of the colossal Buddha at Nara (eighth century), it is recorded in the Temple manuscripts that no less than 500 pounds were used, the value of which would be about £25,000 sterling.

The method by which the surface of copper and bronze were coated with gold depends on the use of mercury, and as the ores of this metal had not then been found in Japan, there is little doubt that the process had been introduced from China, where it seems to have been known for many centuries B.C.

The process is a very simple one. The object of copper or bronze to be gilded was immersed in vinegar made from the juice of unripe plums, until a clean metallic surface was obtained. It was then washed and dried over a brazier, and mercury was applied to it whilst it was still hot. When the surface had been thus amalgamated, the gold was laid upon it in the form of leaves. A stronger heat was then applied, the mercury was volatilised, and the gold left perfectly adherent.

During somewhat later times the most important use of the metal was as a medium of exchange, for which purpose it was employed in the form of gold dust enclosed in quills or small bags, each containing a definite weight.

Objects of solid gold, excepting those of very small size, were seldom made. Gold plate was unknown, and even in the palaces of the wealthiest military nobles, the only vessels of the precious metal, either for use or display, were a few wine cups and diminutive kettles for heating water or wine, and these were by no means common.

The only large vessels of gold known to me are two caskets which were in the Shinto Temple of the Sun Goddess. Placed in the Holy of Holies of the innermost shrine, and containing divine emblems, they were never seen excepting by the chief priest, who alone had the privilege of entering this most sacred portion of the temple.

In 1883, it was decided that they should be melted and replaced by others, and the honour of preparing the new vessels was accorded to the mint.

The old caskets were two simple cylindrical covered boxes, entirely without ornament of any kind, probably not older than the seventeenth century, as on assaying them I found that they were composed of 67·8 per cent. gold and 29·3 per cent. silver, a composition identical with that of the coinage of that date. Their weight was 291 ounces, and value £840 sterling. The new vessels were made of similar form to the old, of rolled sheets of gold, riveted with gold pins. (The alloy, which was used in accordance with my suggestion, was 90 gold, 6 silver, and 4 copper.)

Gold jewellery—in our acceptation of the term—was, as I have already stated, worn but sparingly, so that the use of gold in the art of the metal-worker was practically confined to the decoration of the furniture of the sword, and the fittings of the pipe and tobacco pouch. The small ornaments attached to the sides of the grip of the sword were often made of gold of great purity. One specimen which I analysed contained—

	Per Cent.
Gold	98·1
Silver	1·4
Copper }	0·5
Lead }	

For most objects generally alloys of gold with silver, containing less gold, and approximating in composition to the mint coinages, were usually employed.

In the seventeenth century their composition varied from 84·6 to 87·8 per cent. gold. In the eighteenth, the amount of gold present sometimes falls as low as 65 per cent. In the nineteenth century extremely poor alloys are occasionally found, in which the proportions of gold are reduced to 35 per cent. (8 carats), and even to 12·3 per cent. (3 carats). Yet from the peculiar treatment to which objects of even these poor alloys are subjected, they are undistinguishable in external appearance from those of pure gold.

The sixteenth century is chiefly remarkable in the annals of gold for the first coinage of the metal by the government of

Japan. No specimen of gold coins of an earlier date are in existence, and although they are said to have been occasionally made in the daimiato mints, tradition, usually so prone to refer to remote times all it records, does not ascribe to any a great antiquity. The first government mint for the coinage of gold and silver money was established between A.D. 1579-1580.

One of the first issues of this mint is called an "oban," or specifically "Tensho oban"—Tensho being the name of the chronological period during which it was made.

It is a very large coin, in the form of an oval plate, measuring nearly 7 inches in length and about 4 inches in breadth; its average weight being 5·3 troy ounces, and its average composition—

											Per Cent.
Gold	:	:	:	:	:	:	:	:	:	:	73·84
Silver	:	:	:	:	:	:	:	:	:	:	24·00

Its actual value in our money is £16, 16s. 6d.

There were also smaller coins, which were used for making ordinary payments. In addition to the production of coins, it was always a function of the mint to prepare for the government from time to time large bars of gold called "Homa," which were to be kept in the treasury as a reserve against famine, war, or other calamities. These bars were of the form of an ancient weight, and were approximately of the following dimensions:—Length, 13 inches; breadth, 6 inches; and thickness, 5 inches. Each of these bars usually bore an inscription stating that it must not be used for ordinary expenditure, but only for the requirements of war or famine. The inscription on some was "Peace and treasure endure together," meaning that a reserve against war is a guarantee of peace.

The methods pursued in the early mints for the production of coins are of special interest, as they are for the most part identical with those practised by all workers in gold and silver from those times up almost to the present day, and several are unique in the art of metal working. The operations are all illustrated in detail in the manuscript rolls exhibited: a few of the most important I will now describe briefly.

The Assay Laboratory.—As the gold obtained at the different mines was by no means of uniform composition, it was neces-

sary on its arrival at the mint to determine the actual proportion of gold present in it. The assay was performed by means of the touchstone and a series of small bars or plates of gold alloyed with definite proportions of silver, according to a decimal scale. These "trial" plates were prepared by the government, and were used not only in the mint, but all goldsmiths' wares are said to have been compared with them in order to determine their fineness.

The touchstone, a specimen of which was exhibited, is a small flat piece of black silicious shale. The gold to be assayed was rubbed on the smooth surface of the stone, and the colour of the streaks produced was compared with similar streaks made near them by rubbing on it one or more of the definite alloys. No acids or chemicals were used. This method is still practised by all gold workers, and by it, when the gold is only alloyed with silver, a skilful expert will obtain results not differing in extreme cases more than ten parts in a thousand from assays made by our methods. The operations of coining in the old mints consisted of melting and casting the gold, and hammering it into strips of suitable thickness for coins. The hammered strips were then taken to an assay department, where they were tested for copper by a curious method.

The metal was heated to redness over a charcoal fire, and whilst red-hot was rubbed with a stick of pine wood, and then immersed in water. The presence of copper and its approximate amount was determined by the change of colour presented by the part to which the pine wood had been applied. (So successful were the old operators in the application of this test that it is rare to find more than 0.25 to 0.35 per cent. of copper in any of the gold coins.) If the copper was found to be in excess, the strips were cupelled with lead for its removal. Otherwise they were now cut up with shears into small pieces of the required size and weight, and then stamped.

Owing to the large proportion of silver which the coinage alloys contained, the coins were still nearly white in colour, and it was necessary to give to them a surface of gold. This was effected not by any ordinary gilding process, but by dis-

solving out the silver from the upper layers of the alloy (Fig. 3).

The coins were first painted with a mixture composed of iron and copper sulphates, potassium nitrate, calcined sodium chloride, and resin made into a paste with water. They were then carefully heated to redness on a grating fitted over a charcoal fire. After this they were immersed in a strong solution of common salt, washed with water and dried. Their surfaces now consisted of a layer of pure gold. This



FIG. 3.—Colouring Gold Coins in the Old Mint, Eighteenth Century.

process was followed by the old workers in gold, and with trifling modifications is still practised at the present day.

Silver.—"Gin," or as it is sometimes called by the Japanese "Shiro Kane"—"the white metal"—has been in use in the country from a very early period. It is certain that it was worked by native craftsmen during the early centuries of our era, and possibly in still more remote times, and that then it was more abundant than gold.

The earliest examples of the use of silver known to me are those which are found in the ancient burial mounds. They consist of beads, rings, and other personal ornaments which I obtained from a dolmen in Kawachi. Of somewhat later date are bands of the metal encircling the scabbards of

swords, a small guard, and other sword furniture. The earliest specimen of larger objects is a silver bowl 17 inches in height, to which the date A.D. 766 is ascribed.

From this time until the late mediæval period objects of silver are not very common. The cold and sober colour of the metal unfitted it for the gorgeous display aimed at in Buddhist temples and ceremonies, hence it was used but seldom for their religious vessels and utensils, and when used was generally gilt. So that up to near the beginning of the sixteenth century specimens of a few coinages and a few sword mounts are almost the only examples of its use which are in existence. The impetus which was then given to the decorative arts by the cessation of the civil wars resulted in a marked extension of the employment of silver during succeeding centuries, especially in the form of its alloys with copper, for guards and other sword furniture. And in the eighteenth, but more particularly during last century, numerous objects rarely made of the metal heretofore—such as kettles, vases, and ornaments—have been produced by several noted craftsmen; and not a few of these are masterpieces of chasing and repoussé work, in no way inferior either in beauty of design or delicacy of execution to the best art work of earlier times.

The methods and processes practised by the Japanese in the working of silver are analogous to those which I have described for gold. Its value was determined by means of the touchstone and trial plates of definite alloys of silver and copper, a method not so accurate as for gold, although a skilful expert will ascertain the proportion of the metal present in a rich alloy within $1\frac{1}{2}$ to 2 per cent.

If the silver was too impure for work, it was expelled with lead by a method which I will describe later on.

The native metallurgists were very skilful in conducting this process. I have assayed the silver thus purified very frequently, and the most impure specimen I have ever found contained 98·5 per cent., and the purest 99·7 per cent. of the metal.

In making silver objects, and also for the older coinages, the metal was sometimes used in this pure state, but generally

small quantities of copper were added, not for the purpose of debasing it, but to increase its hardness, and also in order to obtain castings free from vesicular cavities, a matter of some difficulty with the pure metal.

The old sword ornaments and similar objects that I have examined have generally assayed from 94·5 to 97·2 per cent. and upwards of silver.

Later on, especially during the last half of the eighteenth century and the early part of the nineteenth century, a considerable quantity of small bars of debased silver for commercial purposes were made at the old mint, and these were sometimes used by jewellers in the manufacture of ornaments and the like. These poor alloys are, however, never found in silver-work by good artists. When bars of debased silver were cast, the metal was poured into canvas moulds which were set in troughs of hot water.

The reason for this being that the alloy contained so much copper, that if cast in the ordinary way the bars would be coated with a black layer of copper oxide which was difficult to remove. By placing the moulds under water this oxidation was prevented, and castings with a clean metallic surface were obtained.

The castings were, however, of a coppery hue, and this required removal. They were therefore heated to redness, and then plunged into plum vinegar containing common salt in solution. After digestion in this for some hours, they were boiled in plum vinegar without salt, and were then washed with water and dried. By these operations the copper in the alloy was removed from the surface layers, and a coating of pure silver left. The castings sometimes contained only from 13 to 20 per cent. silver, yet when the above operations had been carefully carried out, these low alloys had the appearance of pure silver.

But the chief works by which the old metal-workers of Japan have made themselves famous in the world of art were not executed in either gold or silver, but in their alloys.

Of these the most important are shakudo and shibuichi, the former being an alloy of gold with excess of copper, and the latter of silver with an excess of the same metal.

Shakudo is of a dark copper colour, differing but little in appearance from ordinary bronze, and its value as a decorative alloy is entirely dependent on the beautiful black patina which may be produced on its surface by suitable treatment.

Its composition is given in Table I.

TABLE I.—ANALYSES OF THE ALLOY “SHAKUDO.”

	Gold.	Silver.	Copper.	Lead.	Iron.	Arsenic.	Total.	Analyst.
1	4.16	0.08	95.77	...	...	...	100.01	Kalischer.
2	3.73	1.55	94.50	0.11	Trace	Trace	99.89	Gowland.
3	2.67	2.06	94.90	0.11	...	...	99.74	..
4	2.45	1.24	96.00	0.06	...	...	99.75	..
5	1.52	2.01	96.10	0.08	...	...	99.71	..
6	1.00	1.37	97.40	0.07	...	...	99.84	..
7	0.49	0.29	99.04	...	...	...	99.82	Atkinson.

The presence of not less than 3 per cent. of gold is absolutely essential to obtain the finest black surface with violet sheen, which is seen in the choicest specimens of the alloy.

The pure alloy of copper and gold, the true shakudo, is essentially Japanese, and is unapproached in the beauty and richness of its patina by any alloy of the Chinese, either of old or recent times. Its deep rich tones of black, and the splendid polish which it is capable of receiving, render it alike a perfect ground for inlaid designs of gold, silver, and copper, and for being similarly inlaid in them.

The method by which the black patina is produced is as follows. The object is first boiled in a lye prepared by lixiviating wood ashes, after which it is carefully polished; if necessary, with charcoal powder. It is then immersed in plum vinegar containing common salt in solution, and after being washed with a weak lye is placed in a tub of water to remove all traces of alkali.

After this treatment it is digested in a boiling solution of copper sulphate, verdigris, and water, to which sometimes potassium nitrate is added, until the desired patina is produced.

It may interest you to know that the Japanese are still adding to the number of their curious alloys, the last addition being a variety of shakudo containing no gold.

It has been introduced by my friend and former chief assistant (Mr. Y. Koga, now the chief chemist and assayer of the Imperial Mint), for the preparation of medals for the soldiers who took part in the war with China. It was decided by the government that these medals should be made from the bronze guns captured from the Chinese, but that they must not present an undignified appearance, like a cheap copper coin, but must have a black patina resembling shakudo.

After several experiments he succeeded in producing an alloy with the desired patina by adding to the bronze of the guns small quantities of an iron arsenic speise containing 60 per cent. Fe and 32 per cent. As.

The medals, after being struck and carefully burnished, are boiled in a solution of the following composition:—

Copper sulphate	.	.	.	.	.	.	2.5 grammes.
Verdigris	.	.	.	.	.	.	8.3 „
Water	.	.	.	.	.	.	2.0 litres.

After this treatment they possess a very fine black patina almost rivalling that of shakudo. The above solution does not differ very much from those generally used for that alloy, but it possesses this great advantage, that the burnished surface of objects treated by it is not in the least impaired.

Shibuichi. — Of equal or even greater importance than shakudo, and certainly in more extensive use in ornamental metal work, is the alloy of copper and silver called shibuichi. Its name denotes that it consists of one part of silver in four parts of the alloy, but it is rather a generic than a specific name, and under it must be included several other definite alloys in which the silver and copper are in different proportions.

The composition of the members of this group which I have analysed is as follows:—

I may say here that the alloy most generally employed by the chief art metal-workers was not shibuichi in the strict meaning of the term, but sambo-gin.

The value of this alloy in decorative metal work is like that of shakudo, entirely dependent on its patina. It possesses no special beauty when cast, its colour being that of pale gun-metal or a common pale bronze: but when its surface is subjected to appropriate treatment it assumes a patina of charming shades of grey, which give it a unique position among art alloys. No other affords the artist such a delicate, unobtrusive, and effective ground for inlaid designs of gold, silver, or other metals.

The patina is produced by precisely the same operations which are practised for shakudo, but the solution in which the objects are boiled has a different composition. The most effective solution for the purpose is prepared from that used for the arsenical bronze already described by adding 1 cubic centimetre plum vinegar to each litre.

All the alloys given in the table of analyses yield a grey patina when treated with this solution, but the finest grey tints are only obtained with those containing from 20 to 50 per cent. silver.

Copper and its Alloys.—Copper, or, as it is called by the Japanese, “akagane,” the “red metal,” is the metal *par excellence* of Japan, as in addition to its extensive use as a constituent of bronze, its applications are more numerous than in any other country, and many are unique.

It was first employed in the form of metallic copper, near the beginning of our era, by the builders of the dolmens and chambered tumuli, who made use of it chiefly in thin plates, coated with gold, for the decoration of the sword and person of the warrior, and, as we have already seen, for coating the ornamental iron appendages of the trappings and the cheek pieces of the bits of his horse.

The furnace for the production of copper, which I now propose to briefly describe, is the one that from very early times has been employed in Japan, originally on a small scale, but during the last one or two centuries so extensively that all the industrial metals—copper, lead, tin, and silver—required by the country have been produced by means of it.

It still is in use to a considerable extent, more particularly at small mines and in remote districts, although at the larger mines all the furnaces and appliances of modern metallurgy have been everywhere adopted.

These simple furnaces are so eminently adapted for the use of mining prospectors at the present day, and for the first development of an ore body they may have discovered, that I can confidently recommend their use to any who may be engaged in the search for, or opening-up of, mineral veins. I think it will be admitted by all, that when a prospector has been fortunate in discovering a mineral deposit, if he can send home with his report a few ingots of copper, pigs of lead, or a few bars of silver, the report will be of greater value, and carry more weight at a directors' meeting than if it had not been thus accompanied.

Then as regards the first development of a mine, these simple furnaces are of special importance, as, by their means, he can begin smelting operations and be producing metal at once, and thus gain an insight into the character of the ore, which will be of the greatest assistance when he has to decide on the process by which the metal can be most economically extracted, and the plant which will be most efficient for the purpose.

We will first consider the bellows which are required for working the furnaces. They are of two kinds—one which is worked by hand, the other, a more powerful appliance, worked by the feet. The former is called the “fuigo.” It is the bellows in universal use in Japan for supplying the blast to the furnaces for smelting all metallic ores, excepting those of iron. Its usual dimensions are:—Length, 3 feet; height, 1 foot 10 inches; breadth, 7 inches. It consists of a rectangular box, fitted with a piston, which works backwards and forwards, and has an edge-packing of feathers or fur to prevent loss of blast by leakage. The apertures and flap-valves are so arranged that it is double-acting. The blast-pipe is generally a bamboo stem, terminated by a clay tube or twyer. The other, which is called the “tatara,” is a much more powerful bellows; it is used for large furnaces, and is the one employed by bronze-founders in making large castings.

Fig. 4 represents it in section and plan.

It consists of two air chambers A, A, in some cases constructed of wood, in others of clay, with merely a lining of wood at their sides. The bottom of each chamber is an inclined plane sloping from a central ridge. The top of this ridge is fitted with metal bearings, in which the axle

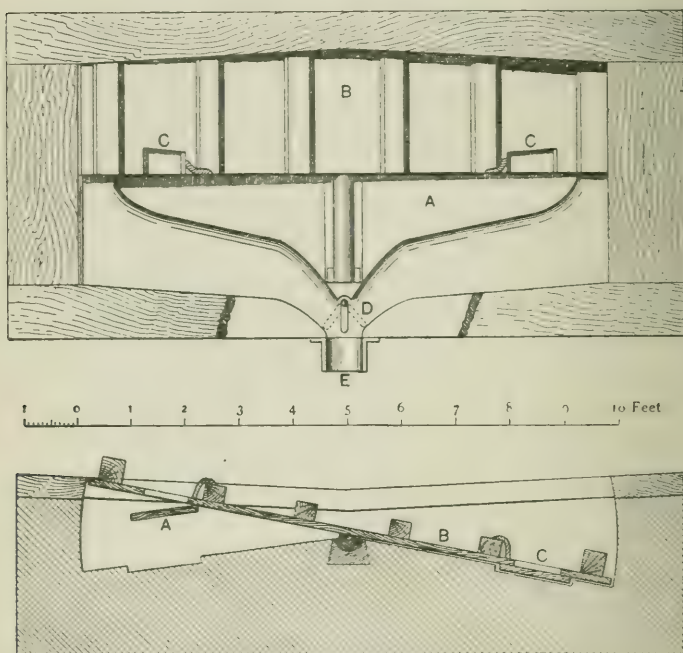


FIG. 4.—Japanese Blowing Machine, called "Tatara."

A, A, air chamber : B, pressure board : C, C, valves of pressure board : D, blast valve : E, blast outlet.

of the pressure-board B works. The pressure-board is made of wood, and is fitted with two valves C, C, opening inwards, one being placed at each end.

About eight or ten persons are required for working one of these machines, and in melting bronze often the whole of the artist's household—men, women, and children—aid in the operation. A rocking motion is given to the pressure-board by the workers stepping alternately on and off either

end, and the air is thus compressed, first in one chamber then in the other, and passes to the blast-outlet E through a channel at the bottom and front of each. At the junction of these channels with the blast-outlet a flap-valve D closes either channel when the opposite half of the pressure-board descends. The workers are aided in stepping on and off by ropes hanging from the roof, which they grasp with their hands, and in keeping time by singing songs which have been specially composed for them (Fig. 5).

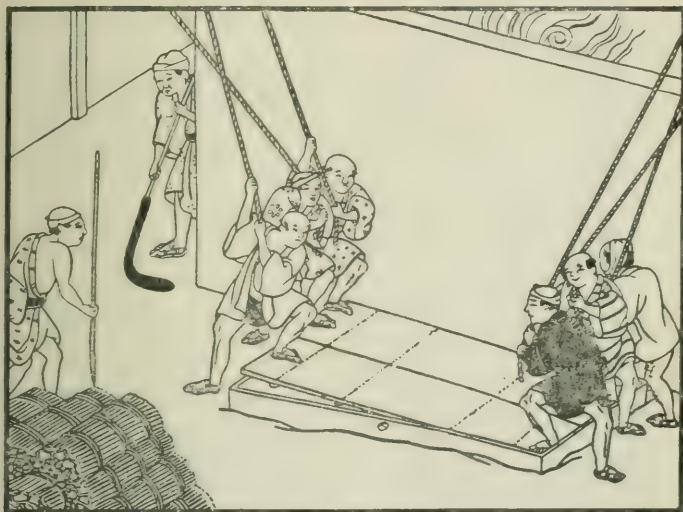


FIG. 5.—Working the Blowing Machine called "Tatara."

The smelting furnace is represented in Fig. 6.

No appliance of primitive metallurgy could be simpler, either in shape or construction, than the Japanese furnace. It is, in fact, a survival of the rude hearths of the men of the Bronze Age.

It consists merely of a hole in the ground, yet by means of it all the copper, lead and tin produced in the country was obtained. As late as 1884 it was practically in universal use, and in that year 8816 tons of copper were produced by its means, and at a total cost at some mines of only £30 per ton, including the expenses of mining.

In constructing a furnace a plot of dry ground is selected. In this an excavation, about 4 feet in diameter and 4 feet deep, is made, and then filled with dry clay carefully beaten down. In the centre of this bed of clay a hole is scooped out

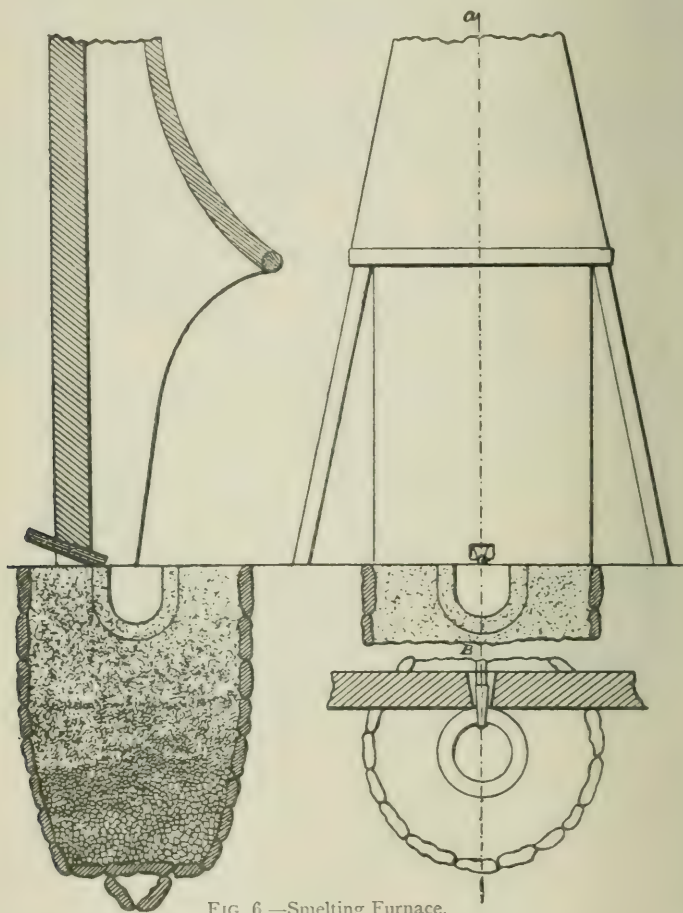


FIG. 6.—Smelting Furnace.

of the shape shown in the diagram. The hole is then lined with a layer of brasque—a mixture of clay and charcoal—about 6 inches in thickness, and the furnace is complete.

The furnace illustrated was constructed in wet ground, so that a foundation for drainage had to be put in.

There are no apertures either for tapping or for the admission of the blast.

The blast is supplied by one or sometimes two of the box-bellows already described, from which it is led by bamboo tubes to the clay nozzle or nozzles which rest on one side of the furnace cavity.

A roughly-made thick cover of clay, 5 or 6 inches thick, is placed on the top of the blast nozzles or twyers, and covers the back half of the furnace. The dimensions of the furnace should be about 18 inches diameter, 14 inches deep.

We will now consider briefly the metallurgical treatment of cupriferous pyrites as carried out in Old Japan, and still practised at small mines. The ore is first roasted in stalls built with any rough stones which are available.

Six hundred pounds of the roasted ore is taken and divided into four parts of 150 pounds each. A charcoal fire is made in the furnace, and as soon as it is well alight a layer of ore is placed over it and the blast gently started; then another layer of charcoal is put on, another layer of ore, and so on, charcoal and ore in alternate layers being added until a rather high pile is formed over the furnace. The blast is then urged, and as the ore gradually melts the materials sink completely into the furnace. The unburnt charcoal and slag are then removed and another 150 pounds of ore is charged in and worked off as before. These operations are repeated until the whole of the 600 pounds of ore has been melted and all the matte obtained is in the furnace. After the matte has been skimmed clean, if it is sufficiently rich in copper, the bellows is brought from the back of the furnace to the front and a twyer is directed on to its surface; the blast is started and continued until the matte is converted into copper. The copper is then taken from the furnace in the form of rosettes in the following manner. A small quantity of water from a brush is sprinkled over the surface of the copper, and the thin solidified crust which is formed is then lifted up by a shovel and thrown into water.

If the matte is not sufficiently rich in copper it is roasted and resmelted.

The copper is nearly always argentiferous.

The silver is extracted in a very ingenious way. The copper is put back into the furnace and melted with lead in the proportion of one part of lead to four of copper. As soon as the mixture of metals is melted a cold iron ball on a long handle is dipped into the metal, the skull of the molten mixture of lead and copper which adheres is lifted out, knocked off, and put aside, and the operation is continued until the whole of the metal has been thus taken out.

This mode of procedure is necessary, as copper and lead do

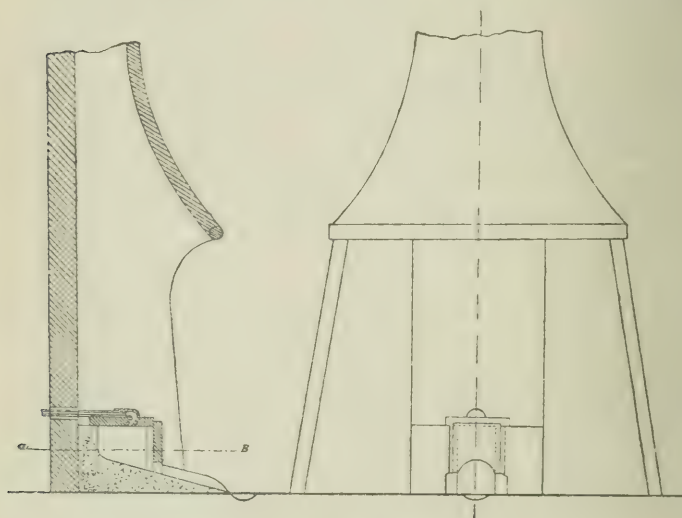


FIG. 7.—Liquation Furnace.

not alloy but only mix, and it is essential that the mixture of metals should be rapidly solidified to prevent the lead from separating out.

The copper lead crusts are then liquated in the furnace, shown in Fig. 7. The furnace is nearly filled with ignited charcoal, and upon this the crusts are laid. A blast of air is then passed through the cover of the furnace, and is so regulated that the temperature is maintained below the melting point of copper but above the melting point of lead. The soft metallic mass which results is gradually pressed by the workmen with an iron tool through the aperture in the front of the

furnace, and as the copper sponge protrudes through this aperture it is pressed still more, the lead gradually trickles out, and is caught in a cavity in the floor. The products are argentiferous lead, and copper with about 8 or 10 ounces of silver per ton. Nearly all the silver, most of the arsenic and antimony, and all the bismuth come out in the lead. Gold is only very partially removed.

This is the only method known to me by which bismuth can be separated from copper by a melting process. The silver is obtained from the lead by cupellation in a simple furnace as follows:—

The argentiferous lead, whether it is obtained from the liquation of copper or by the direct smelting of lead ores, is cupelled in the furnace shown in Fig. 8.

A bellows is placed at one side and the blast is delivered above the middle of the hearth by a twyer bent at right angles.

The hearth of the furnace is composed of wood ashes, from which the soluble salts have been washed out with water.

A square hole about 3 feet wide and 3 feet deep is excavated in the ground forming the floor of the cupellation room. This, after being lined with wooden planking, is filled about two-thirds full with burnt clay, and the rest with the washed wood ashes firmly stamped down, the upper surface of the ash being about level with the surface of the ground. A circular shallow cavity, 12 to 16 inches in diameter and $2\frac{1}{2}$ inches deep, is then made in the surface of the ash and carefully smoothed. Ignited charcoal is then piled in the cavity, and slabs of fire-clay, sometimes incurved at their upper edges, are placed around, forming a rudely circular chamber about 18 to 20 inches in diameter, which is open at the front but closed at the top with a fire-clay slab. The argentiferous lead to be cupelled is now placed on the charcoal, the bellows are started gently, and when the metal has melted and filled the cavity in the hearth the charcoal is pushed away and piled around the molten lead. The lead being thus fully exposed to the action of the blast is gradually oxidised, the lead oxide formed is partly absorbed by the hearth, and together with any scoræ of infusible oxide partly removed by means of a small

skimmer. More argentiferous lead is added from time to time as required, and when all has been oxidised a cake of silver remains on the hearth (Fig. 9).

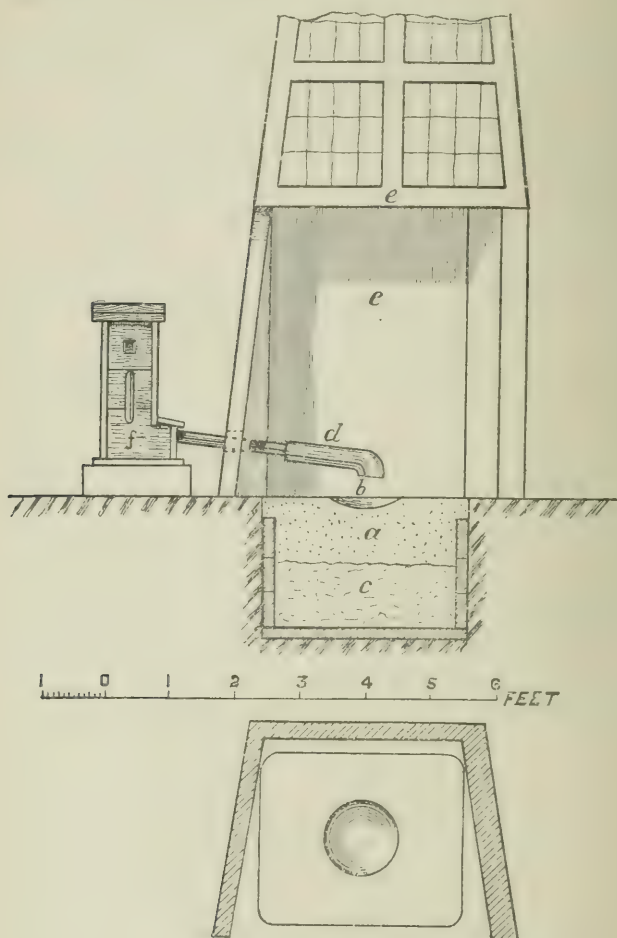


FIG. 8.—Cupellation Furnace (Plan and Sectional Elevation).

In prospecting work the ashes from the camp fire should be carefully saved, washed with water to remove soluble matter, and the washed residue be used for the cupellation hearth.

We will now consider the curious process of refining the

crude copper, after liquation, and casting the refined metal in canvas moulds in hot water.

This has been practised by the Japanese for many centuries, and is another of their unique metallurgical operations. It is now gradually being superseded by Western methods, and will ere long be disused and perhaps forgotten, yet up to 1873 all copper had been cast by it.

The strange manipulation it involves afford us a striking example of the ingenuity of the early Japanese metallurgists



FIG. 9.—The Cupellation of Argentiferous Lead.

in overcoming some of the difficulties which are inseparable from the casting of the metal copper.

The crucible in which the copper is refined is of a peculiar form. (See Fig. 10.) It is made of clay mixed with chopped straw, and varies in thickness from 1 inch to 2 inches.

It is heated in a unique manner by placing the fuel in its interior and above it, and not around its exterior and below it, as is the custom in every other country—a mode of heating which the Japanese have been compelled to adopt on account of the non-refractory character of their fire-clays. This crucible, and all the other appliances exhibited, have been actually used

in the copper refinery of my friend Mr. Sumitomo in Ozaka.

The moulds into which the metal is poured are constructed

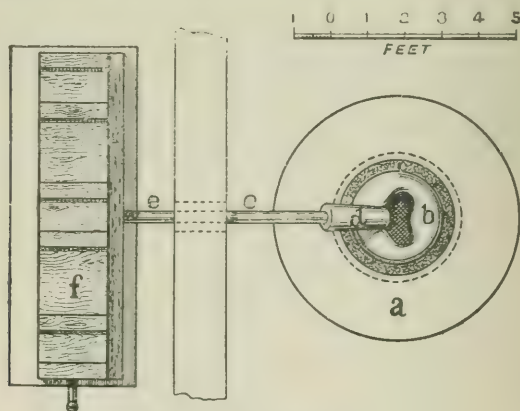


FIG. 10.—Refining Furnace. Plan.

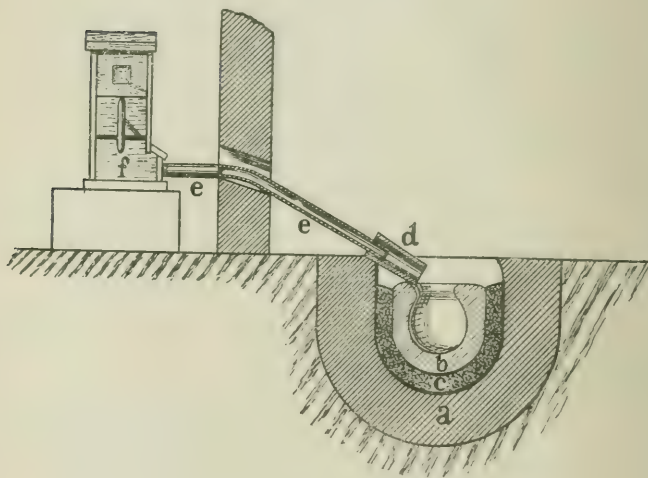


FIG. 10A.—Refining Furnace. Section.

of sailcloth, and are, of course, only adapted for castings which are almost flat and not of great thickness.

The specimen exhibited shows the manner in which the layers of cloth are arranged in a wooden frame for the casting

of rectangular plates. The frame bearing these moulds is placed in a wooden tank measuring 4 feet 6 inches by 3 feet by 1 foot, which is then filled with hot water, and the process of casting is conducted as follows:—

The furnace (Figs. 10 and 10A) is a simple hemispherical hole in the floor of the melting-room lined with a mixture of clay and charcoal.

The crucible, *b, b*, is first embedded in the furnace in powdered charcoal, *c, c*. Lumps of ignited charcoal are then placed in it, and also piled up above it in a low conical heap. The bellows are started, pieces of copper are placed on the heap above the blast-pipe, *d*, and more charcoal is piled over them. The charge of the crucible is approximately 90 lbs., and about eight charges can be worked per day of twelve hours. The copper gradually melts and falls in drops through the blast into the crucible. During the exposure to the air of the blast the impurities contained in the metal are oxidised, and are removed from time to time in the form of slag.

When all the copper has been melted, and the excess of copper oxide it contains has been removed by inserting into it a stout piece of charcoal, the crucible is lifted out of the furnace. The metal is then poured in a full stream through the hot water into the canvas moulds, which are about five or six inches below the surface (Fig. 11).

When each mould is full it is carefully watched by the assistant melter until the metal has solidified. At that instant he quickly seizes the casting with tongs, holds it for a moment in the steam rising from the hot water, and then throws it at once into the lower part of the tank. The momentary exposure of the red-hot copper to the action of the steam produces a thin film of sub-oxide on its surface of a beautiful deep rose colour, which is permanent.

The metal was never cast in ornamental forms, but only in plates, rods, and discs, and these are fashioned into art objects solely with the hammer, punch, and chisel.

The operation is one which requires much care, for if the temperature of the copper is too high, or that of the water is too low, an explosion may occur, which is sometimes attended with very serious results both to the workmen and buildings.

. But these accidents are very rare. The temperature of the water should be from about 150° to 175° F.

In order that the colour may be very brilliant, it is necessary that the copper shall contain a very small quantity of lead—about 0.1 to 0.2 per cent.; and therefore lead is always added to the metal in the pot.

In addition to the ordinary uses of copper for wire, sheets, kettles, pans, and other vessels for domestic and industrial purposes, a large quantity is used for roofing, rain-water



FIG. 11.—Casting Copper.

gutters and spouting, and also as a constituent of bronzes and brasses. I will now ask your attention to the consideration of the important alloy bronze.

Bronze.—From the descriptions which follow of the operations of the Japanese bronze-founder, it will be seen that, whilst in their general features they have much in common with those of the bronze-founder in Europe, they present some differences of great importance. Differences that are chiefly found in certain details of manipulation, which are the results of the conditions under which the Japanese founder

has worked, the composition of his chief alloy, and the nature of his training.

Before proceeding to consider these operations we will first glance briefly at the founder himself.

A knowledge of the principles and practice of his art had to be obtained under a system of apprenticeship, which had much in common with that in vogue in Europe during the latter part of the Middle Ages, and in which drudgery and household work absorbed not a little of his time. During his apprenticeship he was taught every branch of the founder's art, from the rough work of mixing and tempering clay for moulds and the making of crucibles, to the highest stages of designing and modelling objects in wax, and of subsequently casting them in bronze.

The Japanese processes of casting bronze and the appliances used, which I shall now briefly describe, are those which I have seen from time to time in the art foundries of Ozaka during my residence there.

We will first consider the inner portion of the mould called the core. It possesses some peculiar features which are specially characteristic of the methods of bronze-founding practised by Japanese artists. It is open at both ends, and in order that this kind of core may be employed, almost all castings—even of vases, braziers, and similar objects—are cast without bottoms, the bottoms being cast separately and subsequently attached by means of solder.

It is usually fashioned on a wooden framework, the parts of which are ingeniously arranged so that it can be withdrawn as soon as the entire mould has been finished and dried. This framework, an example of which is shown in plan and section in Fig. 12, is constructed as follows:—

A sufficient number of flat strips of wood, A, A, are prepared, their external edges being roughly cut to the shape of the interior of the article to be cast. Two circular discs of wood, B, B—each in two segments and furnished with a central hole—are also prepared to form the top and bottom of the frame. The above strips are then arranged around the peripheries of the discs and are kept in position by means of wires or cords. A bar of wood, C, of suitable length, is then passed through

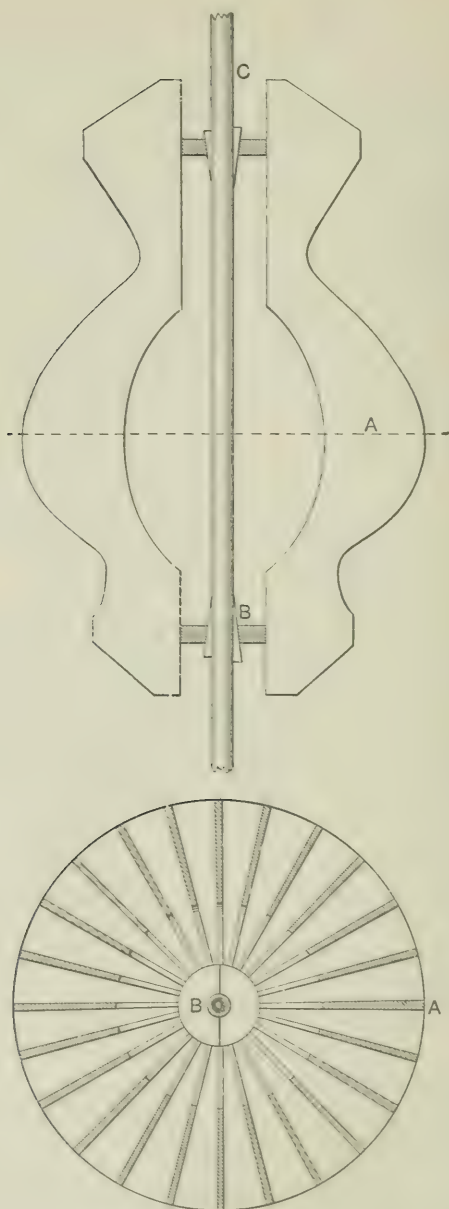


FIG. 12.—Removable Core Frame.

the apertures in the discs, and the framework is firmly attached to it by wedges. The object of this bar is to enable the core to be moved about or revolved, and so to facilitate the work of the modeller. Thin strips of bamboo, or sometimes a cord of straw, or both, are now bound round the exterior of the frame. The core is then moulded on it to the proper thickness with a mixture of burnt and raw clay and rice husks, applied in several layers, the lower layers being coarser and more porous than those above them, and the exact form is given to it by one or two final coatings of clay mixed with sand. After the core has been dried the vase or other object with all its decoration is modelled on it in wax of the proper composition. When the model is completed, it is coated with a thin layer of fine clay applied with a brush with great care. After drying, other layers are similarly applied, until the crust is sufficiently thick to permit additional layers of somewhat coarser clays to be put on with the hand and tools, to give the requisite strength to the mould.

The mould is then dried very slowly in a warm part of the foundry. When dry, the wooden core frame is removed, and the wax is then melted out by means of a carefully regulated charcoal fire, by which both the hollow core and the outside of the mould are heated, and at the same time all traces of moisture are expelled, and its walls baked hard.

The furnaces and appliances which are used by Japanese artists for melting and casting bronze are of a very simple character.

A typical cupola furnace, which is that which was actually used in the casting operations to be described subsequently, is represented in Fig. 13.

It is very ingeniously constructed of cylindrical segments. The lowest, which forms the hearth, consists of a cast-iron pan lined with fire-clay. It is furnished with an aperture G in front, for tapping out the metal, and another at the back for the insertion of the twyer, through which the blast is introduced. Each of the other segments consists of a cylinder of fire bricks or slabs, cemented together with fire-clay, and firmly bound with iron bands.

There is no special charging door, the fuel and metal being simply thrown into the open top of the furnace.

In all well-arranged foundries these segments, with their accompanying hearths of various sizes—generally from 1 foot to

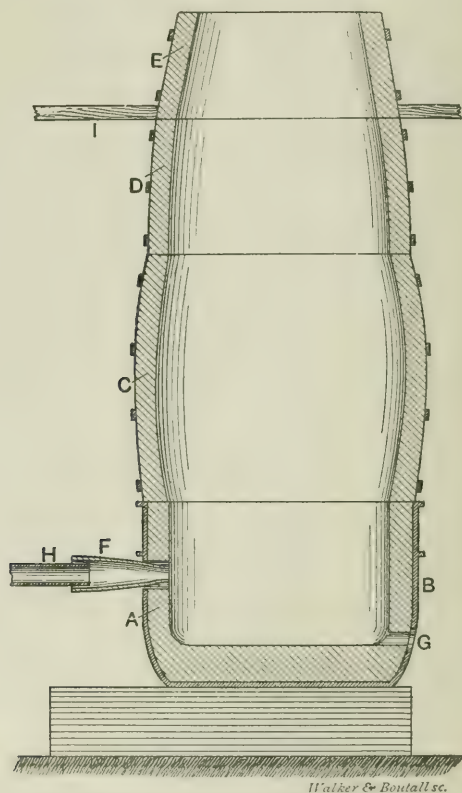


FIG. 13.—Typical Cupola Furnace for Melting Bronze.

A, lower segment of the furnace; B, iron pan enclosing the furnace; C, D, E, upper segments; F, tuyer; G, tap-hole; H, pipe leading the blast from the blowing machine; I, charging floor.

2 feet 3 inches in diameter—are always ready, so that a furnace can be built up without delay at any time for either large or small meltings.

The cupola is erected by placing the hearth-segment on a platform of brick about one foot high, so that the tap-hole may

be of a convenient height for tapping. Upon this segment one of the others is placed and luted to it with fire-clay, another is placed on this and similarly luted, and others are added if necessary, until the furnace is of suitable height.

The advantages which this method of erecting cupola furnaces possesses for small foundries, where the work is of an irregular character, and where castings are often urgently needed which are too large for crucibles and too small to justify the lighting up of a large permanent cupola, are self-evident.*

When a Buddhist divinity, or a bell of unusual weight, was required for a temple in any locality, the whole of the operations were conducted on the spot. Temporary sheds for the modelling were erected in the temple grounds. The furnaces and blowers were transported thither in segments; sometimes the latter were even made by the local carpenters. If the casting had to be made in one piece, the necessary number of cupola furnaces, each with its blower, were erected around the mould. The cost of the blast was nil, as the services of any number of eager volunteers from the crowds which congregated at the temple festival on the day of casting were readily obtained for the meritorious work of treading the blowing machines. In this way the great bells and colossal images were cast.

For my description of the operations of casting, I have selected the casting of a brazier in the mould shown in Fig. 14, as it is a typical example of Japanese practice, and I was present in the foundry during the whole of the operations.

The bronze was melted in the cupola furnace (Fig. 13). Charcoal was used as fuel, and the blast was produced by a "tatara" worked by eight persons.

From an early hour in the morning, and whilst the melting was proceeding, the foundry staff was engaged in preparing the moulds for the reception of the metal by heating them to redness. This was effected in the following manner. The

* A foundry cupola constructed on the same principle, *i.e.* in portable segments, has been recently adopted in America for repair work in industrial plants.—*American Machinist*, August 31, 1905.

mould (Fig. 14) was placed on five or six bricks, H, H, to raise it above the earthen floor of the melting-room. Its ingates, C, C, C, C and D, D, D, D, were closed with stoppers of clay, and the conical tubes, F, F, were fitted over its air outlets, E, E, to prevent any fuel from falling into them. A wall of fire-clay slabs, G, G, was now built up around it, the slabs being kept in position by hoops and bands of iron, and an external luting of clay, a space about three inches wide at its

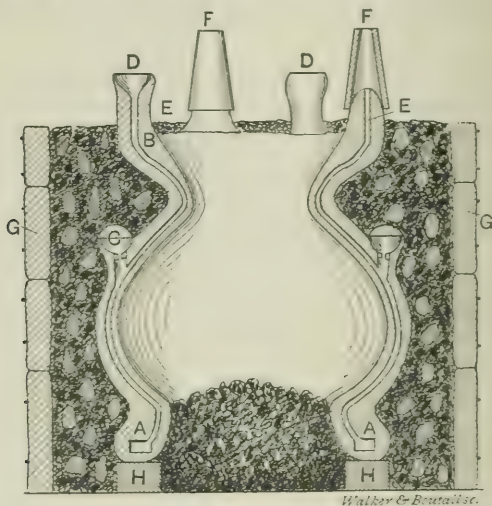


FIG. 14.—Mould with Open Core, showing the Mode of Heating it.

A, A, outer wall of the mould.
 B, B, inner wall of the mould (or core).
 C, C, lower ingates.
 D, D, upper ingates.
 E, E, vents or outlets for the air and gases.

F, F, fire-clay tubes.
 G, G, fire-clay slabs.
 H, H, firebricks.
 I, I, ignited charcoal.

narrowest part, being left between the inside of the wall and the outside of the mould. A charcoal fire was then made on the floor below the mould, and the space between the wall and the mould was completely filled with burning charcoal, which was mixed with fragments of brick and crucibles to prevent the heat from becoming too intense. The interior of the core was also partly filled with the same mixture. The mould was kept at a red heat for more than two hours, by which time the metal was nearly ready. The wall of the clay slabs and the draught tubes were now

rapidly taken down, and the fire was raked away. The bricks, H, H, supporting the mould were carefully removed, and the holes through which the wax had run out stopped up with fire-clay. Large stones were now piled around its base to steady it, and the stoppers were removed from the ingates.

The mould was now ready for receiving the metal.

The bronze was then tapped into four iron ladles, each of which was held by a workman. The workmen then took up their positions opposite the lower ingates, and on a signal being given poured the contents of their ladles simultaneously into the mould. The quantity of metal had been very accurately estimated, as it just reached about half-way up each ingate. These ingates were then closed with clay stoppers luted in with fire-clay. Three of the ladles were filled again, and poured in the same manner as before, but into the upper ingates, completely filling the mould. The mould was allowed to stand for six hours before breaking it from off the casting.

The alloys used.—The success which the Japanese artist has attained in the execution of his famous masterpieces in bronze is not, however, solely due to his methods of modelling and casting, but is partly dependent on the physical character of the alloys he has used. His alloy, *par excellence*, is called “karakane”—which signifies “Chinese metal”—this name having been given to it because it is believed not to have originated in Japan, but to have been introduced from China.

The name karakane does not, however, designate any definite alloy. It has a generic rather than a specific signification, and is applied to a very varied group of mixtures of metals of the copper-tin-lead series, in which, as will be seen from the table of analyses, the proportion of copper may range from 71 to 89 per cent., of tin from 2 to 8 per cent., and of lead from 5 to 15 per cent. It will also be seen from the table that the presence of lead as an important constituent is one of the characteristic features of its composition.

The presence of arsenic and antimony, both of which are often found in considerable amounts in these alloys, is not due to the use of impure metals, as might be conjectured, but

TABLE III.—ANALYSES OF JAPANESE BRONZES ("KARAKANE") AND ALLIED ALLOYS.

Description.	Analyst.	Copper.	Tin.	Lead.	Arsenic.	Anti- mony.	Zinc.	Iron.	Silver.	Sul- phur.	Gold.	Nickel.	Total.
1. Temple bronze	Maumené	88.70	2.58	3.54	...	0.10	3.71	1.07	...	...	...	...	99.70
2. Incense burner; 18th century	Gowland	86.85	1.76	9.13	1.15	0.40	nil	0.33	0.079	...	trace	...	99.699
3. Temple bronze	Maumené	86.38	1.94	5.08	...	1.61	3.36	0.67	...	...	...	...	99.64
4. Vase, 18th century	Geerts	85.3	4.7	4.7	trace	...	...	1.1	...	...	...	...	100.0
5. Cannon, 18th century	Gowland	84.00	12.68	3.92	...	...	...	...	...	...	...	...	100.00
			by diff.										
6. Vase, 18th century	Geerts	83.70	5.38	7.80	trace	...	0.185	0.65	...	...	...	...	99.38
7. Coins, "Bunkyu," 1863	Gowland	83.10	3.21	11.22	1.50	0.49	nil	0.27	0.06	0.38	trace	...	100.23
8. } Old bronze ornamental	Morin	83.09	3.23	11.50	0.25	...	0.50	0.22	...	...	trace	...	98.79
9. } vessels, probably vases		82.90	2.64	10.46	0.25	...	2.74	0.64	...	...	...	...	99.63
10. } Modern ornament; a tortoise		82.72	4.36	9.90	trace	...	1.86	0.55	...	...	...	...	99.39
11. Coins, "Tempo," A.D. 1835 to 1870	Roberts-Austen and Wingham	81.62	4.61	10.21	...	...	...	...	...	...	...	...	99.08
12. Vase (?), old	Gowland	81.31	8.26	9.74	0.18	0.3	0.19	0.6	0.037	0.08	...	...	99.887
13. Temple bronze	Morin	81.30	3.27	11.05	trace	...	3.27	0.67	...	...	...	...	99.56
14. Coins, "Do-sen," A.D. 1636 to 1768	Maumené	80.91	7.55	5.33	...	0.44	3.08	1.43	...	0.31	manga- nese	...	99.05
15. Vase, or ornament	Gowland	77.30	4.32	15.33	1.14	0.31	nil	1.01	0.06	0.52	trace	...	99.99
16. Temple bronze	Kalischer	76.60	4.38	11.88	...	...	6.53	0.47	...	...	...	...	99.6
17. Ornament	Maumené	72.09	5.52	20.31	trace	...	0.67	1.73	...	...	...	...	100.32
18. Mirror, 17th or 18th century	Geerts	71.00	5.50	20.35	...	...	1.34	1.84	...	...	...	...	99.3
19. Mirror, modern	Gowland	95.04	0.58	3.19	0.14	...	...	0.04	1.13	0.04	trace	...	100.6
20. Bronze for soldering copper	Atkinson	76.28	23.64	0.13	...	...	...	...	...	...	...	...	100.05
21. Mirror, modern	Hochstetter Godfrey	75.05	16.95	7.63	...	...	...	...	...	...	...	...	99.63
22. Bronze for soldering copper	Hochstetter Godfrey	67.87	29.92	0.89	...	...	...	1.19	...	...	...	...	99.87
23. Solder for bronze	Hochstetter Godfrey	37.04	1.01	1.01	...	...	61.63	0.25	...	...	...	...	99.93
24. Brass coins, "Shimon-sen," A.D. 1768 to 1860	Gowland	75.62	0.73	2.85	1.99	0.14	16.54	1.76	0.016	0.00	trace	...	99.736
25. Brass temple vase, 18th century	Gowland	74.52	0.79	5.50	0.12	trace	19.14	0.15	...	trace	...	...	100.22
26. Yellow bronze, "Sentoku"	Roberts-Austen and Wingham	72.32	8.126	6.217	...	...	13.102	0.170	...	...	bismuth	0.065	100.000
							by diff.				trace	...	

to the addition of a pseudo-speise—a by-product of the de-silverisation of copper with lead—which contains 11·4 per cent. arsenic and 4·3 per cent. antimony. It was added to the alloy in order to increase its hardness, without diminishing its fusibility, and to obtain in the castings a sharper impression of the mould than was possible with the copper-tin-lead alloy alone.

The chief characters on which the value of the Japanese copper-tin-lead alloys as art bronzes depend, may be briefly stated as follows:—

1. Low melting point. This is of special importance to the Japanese founder, owing to the fusible nature of the clays and sands of which his crucibles and moulds are made.
2. Great fluidity when melted compared with the sluggishness of copper-tin bronzes.
3. Capability of receiving sharp impressions of the mould.
4. Contraction on solidification is not excessive.
5. Peculiar smooth surface.
6. The readiness with which they acquire rich patinas of many tints when suitably treated.

The advantages resulting from the above properties will be obvious to all artists in bronze. They are chiefly the result of the use of lead as one of the chief constituents of the alloys. The low melting point of these bronzes, their fluidity when melted and the facility with which they acquire certain patinas, are entirely due to the use of this metal.

The copper-zinc alloys, “Shin-chu” or brass (Table III. Nos. 24 and 25), have not been much in favour among artists. They were unknown in Japan before the establishment of Buddhism, and were probably introduced contemporaneously with that religion from China (sixth century A.C.).

Their use in art has been almost exclusively restricted to the production of the ceremonial vessels and utensils of temples and shrines, and especially for the “Go-gusoku,” or five ornaments of the Buddhist altar.

Even when a yellow metal is needed for the purposes of

decorative ornament brass is seldom used, copper coated with gold being preferred, the rich colour and quality of the gold surface being more pleasing to the Japanese than the harsher tones of the copper-zinc alloy. Hence there is scarcely a single example in the country of any great work of art executed in brass.

Occasionally the yellow bronze, "Sentoku" (Table III. No. 26), consisting of copper, tin, and zinc—an alloy occupying an intermediate position between "Karakane" and brass, is used instead of the latter alloy. It is, however, probably not older than the fifteenth century.

From the outline I have just given you—I fear a very imperfect one—of the methods of casting bronze in Japan, it will be seen, as I have just said, that they do not differ very greatly from ours. The chief differences lie in the use of the artist's model itself, in the preparation of the mould, in the heating of the mould, and in the composition of the bronze. All these we can imitate; but the special excellence of Japanese bronze castings, the faithful reproduction of the wax model, the comparative absence of retouching, and the delicacy and vigour of the relief decoration are not due solely to these, but are the results of a combination of conditions which are only of exceptional occurrence here. Chief among these is the nature of the Japanese people, the intense feeling and love of art with which they have been imbued for centuries past, and their just and enthusiastic appreciation of faithfulness in work. These qualities have made every workman an artist. Hence the patience and marvellous skill which we see displayed in his work, not only on great works of art, but on every common article which is used for domestic purposes. Beside these, there is an *esprit de corps* in the staff of a Japanese foundry which is not always found in European foundries, the outcome of which is that an amount of painstaking care almost incredible is exercised by all, so that the work shall be as perfect as they can make it, and worthy of the renown of their master. But at present modern Japanese workers in metal work are in an adverse environment and under many disadvantages unknown to their predecessors. In the early centuries religious enthusiasm, the quiet seclusion of

the monastery, and the patronage of a powerful priesthood stimulated and supported the old artists in their work, so that all their powers were put forth in the execution of the masterpieces of those times. In later days the same result was achieved under the system of feudalism which prevailed in the country. Workers in metals were attached to the courts of the great territorial nobles; their incomes were secure, they were free to work out their designs as they wished, and need only do so when they felt inspired. During recent years the Emperor has done much for the encouragement of a select few of the chief workers in the revival of their old art, the result being that some of the objects of modern work which adorn the imperial palace are of extreme beauty. But for the great majority of workers there is no such patronage, yet the art worker in metal must live, and to live means for too many that they must waste their talents in producing objects, in the design and decoration of which they are hampered by the demands of Western commerce. Nevertheless the old art is only dormant, and not dead. The number of craftsmen who follow in the footsteps of the famous artists in metal of a bygone age is increasing, and objects in copper, silver, gold, and their alloys which equal those of the older masters in graceful form and sober ornament are again being produced.

[The lecture was illustrated by diagrams and lantern slides, and the appliances which had been actually used in the operation of refining and casting copper were exhibited. Figs. 1-14 are reproductions of certain of Professor Gowland's slides, and for permission to publish these in the *Journal* acknowledgments are due to the Institution of Mining and Metallurgy, Society of Antiquaries, Society of Chemical Industry, and the Royal Society of Arts.—ED.]

GLASGOW MEETING.

THE THIRD AUTUMN MEETING OF THE INSTITUTE OF METALS was held in the Natural Philosophy Building of the University of Glasgow on Wednesday and Thursday, September 21 and 22, 1910, Sir GERARD A. MUNTZ, Bart., President, in the chair.

RECEPTION OF THE INSTITUTE.

Professor ARCHIBALD BARR, occupying the chair at the opening of the proceedings, said he had been asked, as Chairman of the Local Committee, formally to take the chair, and as soon afterwards as possible to vacate it to Sir Gerard Muntz. He wished to say a word of welcome to those who had come from a distance, and to express the hope that the meetings and the visits to works, and the various entertainments provided, would make the meeting successful and enjoyable.

Principal Sir DONALD MACALISTER, K.C.B., said his pleasant duty was to offer the meeting, on behalf of the University of Glasgow, a very cordial welcome to its walls. When they heard that the Institute of Metals was about to visit Scotland for the first time, and understood that it had chosen the most important city in all Scotland for its meeting-place, the authorities of Glasgow University were most willing and even desirous that the meeting should be held under their roof. As the members were aware, the University, so far as the limits of its means extended, took all branches of knowledge to be within its province, and both the University and the Technical College of the city took especial interest in the applications of knowledge to industry and commerce in their various forms. It was understood that the efforts of the Institute were in the direction of applying the best and latest scientific knowledge to the improvement of metallic industry and commerce. Naturally, therefore, the University felt that it was most appropriate that the Institute should pursue its discussions in that home of science; and through the kindness

of Professor Gray they were able to put at the disposal of the Institute one of the finest departments of the University concerned both with science and with its applications. Those buildings were erected for the study of physics, taking that term in its widest sense. The study of physics in Glasgow University was associated with the name of the late Lord Kelvin, and the traditions he established had enshrined his name among their most cherished memories. Those traditions would be carried forward in that building, which Lord Kelvin lived to see and to inaugurate, though he did not actually work in it, by Professor Gray and his able assistants. Amongst the researches continually carried on there, with which the Professor and his son had long been associated, were those on certain recondite properties of metals, of which possibly they might hear something in the course of the meeting. His (the speaker's) part in the work which specially engaged the Institute's attention was very limited indeed. It referred only to the extraction of the precious metals from the pockets of sympathetic citizens of Glasgow, or from more refractory sources, for the purposes of the University. If the researches of the Institute would enable them to show him how to improve the method of extraction, so as to promote the subsequent deposition of the product in the bank, that result would ultimately prove to be a benefit to science and its practical applications. He again gave them a very hearty welcome on behalf of the University to that hall; and assured them that the University of Glasgow was proud to have the opportunity of entertaining them on the occasion of their first visit to Scotland.

Sir GERARD MUNTZ, Bart., replying, said that on behalf of the Institute he had to thank Professor Barr, as representing the Local Committee, for their kindness in asking the Institute to hold their autumn meeting in that great city. They felt that in coming to a city like Glasgow they were coming to one of the greatest centres having to do with the use of non-ferrous metals, and they hoped also that the result of the visit would be to increase the number of their members. If there was a place where research in regard to non-ferrous metals was necessary, it was in a place like Glasgow, where the use

of brass, copper, and copper alloys was in daily operation. They hoped that many people, not now members, might be induced to join the Institute, after they had had an opportunity of coming into closer touch with the Institute through that visit, and through the reading of the papers. It was to be hoped also they would take part in the discussions. He thanked them most heartily on behalf of the Institute for the trouble taken by Professor Barr and the members of the Local Reception Committee in preparing for their entertainment outside the University. Having had experience of the visits of similar institutions to Birmingham, he knew that it was no light task to prepare a programme of entertainments for visitors, and to arrange for their hospitable entertainment. It entailed a very considerable amount of work. He could assure Professor Barr that the efforts thus made were most highly appreciated by all the members. With regard to the remarks of Sir Donald, he had to thank him for the courtesy shown them by the University, in placing that magnificent hall and buildings at their disposal for the meetings. The venue of the meetings was, of course, a matter of interest to the Institute, and as members they all felt that in coming to the Glasgow University they would stand upon what might be called scientifically historical ground. The associations of that University with the world of science were such as might encourage their members to the greatest efforts in making that meeting of the Institute generally worthy of such a reception. He hoped further that their presence might be of some service in encouraging the young men of Glasgow to follow scientific research at the University, and to become students determined to learn all they could in the realm of science. They would have an opportunity of seeing how much there was to learn, how little was known at present, and how very wide a field was still in front of all of them. On behalf of the Institute he thanked their Glasgow friends most heartily for their kindness and for the reception that had been offered.

The PRESIDENT then proceeded to occupy the chair which had been vacated by Professor Barr.

The SECRETARY read the minutes of the previous meeting held in London on May 24, 1910, which were found to be a correct record, and were signed by the Chairman.

ELECTION OF MEMBERS.

The SECRETARY read the following list of names of candidates who had been duly elected members of the Institute:—

NAME.	ADDRESS.	QUALIFICATIONS.	PROPOSERS.
Andri, Alfred	Herstal-near-Liege, Belgium	Engineer; General Manager, Fabrique Nationale d'Armes de Guerre	W. H. Johnson. R. Kaye Gray. E. Ristori.
Blundell, Frederick Hearn (<i>Student</i>)	199 Wardour Street, W.	Gold, Silver, and Platinum Refiner	C. H. Wilson. W. R. Barclay. J. Howard Wilson.
Crawford, William Mitchell	41 Kelvinside Gardens N., Glasgow	Interested in the commercial side of brass and copper industries	Sir G. Muntz, Bt. R. M. Sheppard. William Weir.
Gillett, Horace W.	The Aluminium Castings Co., Detroit, Mich., U.S.A.	Research Chemist	W. H. Johnson. J. T. Milton. E. Ristori.
Jack, Henry Joseph	60 London Wall, E.C.	General Manager, Aluminium Corporation Ltd.	H. H. A. Greer. John H. Wilson. Alex. Wylie.
Mendenhall, J. B.	2522 Cleveland Av., Kansas City, Mo., U.S.A.	Special Representative, Metal Dept. National Lead Co.	R. Kaye Gray. W. H. Johnson. J. T. Milton.
Stutz, R.	27 Martin's Lane, Cannon Street, E.C.	Managing Director, Thermit Ltd.	J. Echevarri. W. M. Morrison. Arthur Jacob.
Thompson, Robert	155 Fenchurch Street, E.C.	Partner, Thompson Bros., Engineers and Bronze Manufacturers	T. Bolton. J. Preston. J. T. Milton.
Thompson, William Henry	155 Fenchurch Street, E.C.	Partner, Thompson Bros., Engineers and Bronze Manufacturers	T. Bolton. J. Preston. J. T. Milton.

LOCAL SECTIONS.

The PRESIDENT said that although they had those new members, they were still, like Oliver Twist, desirous of receiving more. They would find in their envelopes, just supplied, forms of application for membership, and the Council hoped

that the members would utilise those forms to the best possible advantage. If they thought any of their friends would like to be members, he hoped they would do what they could to get them to join. There was no time like the present. The larger the number the greater would be their pleasure in accepting them, and he hoped they would use their best endeavours to secure recruits to join the ranks of the Institute. The Council had acceded to a request emanating from a number of Midland members for the establishment of a local section in the Birmingham district. As they were aware, that question of local sections was one that had previously had the consideration of the Council, and had now been brought before them by Birmingham members who had found sufficient numbers interested to enable a local section to be created. It had now been created, and was in being, and would shortly commence its labours. He would be very pleased indeed if Glasgow would follow Birmingham's lead. As every one knew, they always looked to Glasgow to give them a lead in such matters, but he hoped in this case Glasgow might follow Birmingham. The establishment of a local section must be a great advantage to the Institute in general, because it kept the members in touch with each other, and kept alive the spirit of association. It was really a long time to keep things alive between the spring and autumn meetings, and by keeping things going, the local sections would enable the members to discuss matters with their colleagues and to consider any subjects exciting interest which might occur and in fact which were almost sure to occur. An event might arise in which some member was interested, and unless it was discussed it was very liable before the half year had elapsed to go into the limbo of ancient history, and to be forgotten. He was very pleased that that local section had been established in Birmingham, and he trusted that every district in which there was a sufficient number of members would take a similar step.

READING OF PAPERS.

Papers were then read by Mr. Alexander D. Ross, M.A., B.Sc. (Glasgow). Messrs. G. D. Bengough, M.A. (Liverpool),

and O. F. Hudson, M.Sc. (Birmingham); Mr. Donald Ewen, M.Sc., and Professor T. Turner (Birmingham). Each paper was followed by a discussion, a hearty vote of thanks being accorded in each case, on the motion of the President, to the respective authors. The meeting then adjourned until 10 o'clock on Thursday morning, September 22, 1910.

SECOND DAY'S PROCEEDINGS.

THURSDAY, *September 22, 1910.*

The Second Session of the General Meeting was held in the Natural Philosophy Building of the University of Glasgow on the morning of Thursday, September 22, Sir GERARD A. MUNTZ, Bart., President, again occupying the chair.

The PRESIDENT, in opening the business of the session, formally advised the members that the incorporation of the Institute was now completed, and that, in accordance with the law, they were required to hold their Statutory Meeting within three months. The Council had fixed October 11 as the date of that meeting, which would be held in London. It was a formal meeting, but quite essential, and it was merely necessary to have a sufficient number to form a quorum. Information as to time and place would be sent to members in due course.

At the Statutory General Meeting they proposed to present their nominations for next year's Council. It would be within the knowledge of the members that members could nominate any person for the Council, and the members would in due course receive a list of the people whom the Council proposed should be candidates for office in the following year.

The Council had also fixed the date for the Annual General Meeting, which would be held in London on the 17th and 18th of January 1911, and it was proposed that the Institute should hold its Annual Dinner as last year, this to take place on the conclusion of the first day's proceedings, namely, on the 17th of January.

The PRESIDENT then referred to the loss the Institute had suffered in the death of one of their Vice-Presidents, Mr. J. B. Bonner. He moved that the Institute pass a vote of condolence with the family of Mr. Bonner in their bereavement.

Sir WILLIAM WHITE, K.C.B., F.R.S., said the President had asked him formally to second the vote. He did so quite willingly, because Mr. Bonner was one of their first Vice-Presidents, and had shown his interest in the Institute in a very practical way. In his position as Chairman of the British Aluminium Company, he had also greatly aided research on the alloys of aluminium promoted by the Institution of Mechanical Engineers and carried out at the National Physical Laboratory. That sort of research was of the greatest value to those in charge of great industrial undertakings.

At the suggestion of the PRESIDENT the vote of condolence was adopted by members rising from their seats.

The PRESIDENT made the announcement that Dr. Beilby and Professor Barr had accepted seats on the Council. That would greatly add to the strength of the Council, and he considered that they had every reason to congratulate themselves that Dr. Beilby and Professor Barr had been good enough to accept that office. He had already told them they need not consider it a burden if it was inconvenient to them to be always present at Council meetings. Even if they could not regularly attend, the addition of such names to the list of officers would be a source of strength to the Institute. He had further to announce a decision of the Council, which he thought would cause general gratification. Sir William White had kindly seen fit to accede to the earnest request of the Council that he should accept the position of being their first Fellow. They were empowered to appoint Fellows of the Institute, and that right enabled them to award Fellowships in acknowledgment of services to the Institute. That applied not only to services in respect of science and on scientific lines, but to general services of great value. He thought no

man at present had approached Sir William White in earning the gratitude of the Institute. He came into the breach—if indeed there was a breach, for at that time there was hardly a wall up to make a breach in—anyhow he came as the first President and took up the work of the Council. In fact, he really practically started that Institute. If they had not had Sir William White behind them, he doubted if the efforts of those instrumental in originating the Institute would have taken the form or have developed with anything like the rapidity which had marked the progress of the Institute. They were all extremely glad in being able to put the name of their honoured first President on the list as the first Fellow of the Institute of Metals.

Sir WILLIAM WHITE said he had already thanked the Council for the honour they had conferred upon him and they had confirmed by their applause in making him the first Fellow of the Institute of Metals. He was most grateful for that distinction, and would beg to assure them that although, as he told them on the previous evening, he had become through the lapse of time and the entry of another President an “extinct volcano,” his interest in the Institute was as great as ever. He believed such an Institute was really needed. They were told in some quarters at the time they started that such an Institute was redundant; that there was no need for more metallurgical, scientific, or technical institutions, because those already in existence entirely covered the ground. That view had been absolutely disposed of during the last three years. The Institute had fully justified the expectations of those who were its founders. He could claim to be one of the original founders, and they knew how the idea had originated, as well as the names of the men to whom the country owed so much for framing a scheme for the establishment of the Institute of Metals. In a very early stage he was asked to take a hand in the matter. If he might venture to say so, his career was an illustration of the danger of allowing the thin end of the wedge to be introduced. He was simply asked to take the chair at the first meeting held for the origination of the Society. Before that meeting

ended he found himself, in spite of very strong protest, the Institute's first President. So he would warn all those who were asked to take chairs to beware of the undertaking, and to make up their minds at the preliminary stage whether they intended to go further. He had gone a great deal further, and was happy to have been able to aid in any way starting an Institute which for its age compared favourably with any technical institute within his own knowledge. Its future, they might be assured, would depend upon members, who alone could determine what its rate of progress would be. Speaking, as he was, in Glasgow, he would say that the greatest expectations as to future increase of membership must lie with two classes, viz. the users of metals and the leaders of the metal trade. On the scientific side the Institute was extremely strong already, as their Proceedings clearly showed. On the side of the metal trades they were fairly strong. They were hoping to be stronger, and the presence of Sir Gerard Muntz in the chair must greatly promote that growth. Already there had been a movement in the metal trades in the direction of franker interchange of opinion, and that movement had been a surprise to those who knew what the conditions were a short time ago. On the side of the users, whose name was legion, they had not done so well as they ought to have done. If he might venture a suggestion, and speaking as one whose most active work for the Institute was necessarily ended, he would venture to say that present members could do a great deal if they would fully make known the objects and scope of the work of the Institute to friends engaged in various branches of industry and endeavour to secure wider interest and help. In conclusion, he wished again to thank them for their great kindness.

READING OF PAPERS.

Papers were then read by Mr. F. Johnson, M.Sc. (Birmingham), Dr. Cecil H. Desch, D.Sc., Ph.D., and Mr. H. S. Primrose (Glasgow). Each paper was followed by a discussion, a hearty vote of thanks being accorded in each case, on the motion of the President, to the respective authors.

CONCLUDING BUSINESS.

The PRESIDENT said they had now concluded their work for the morning, and they had come to a matter in which he was sure they would all be anxious to take part, namely, the votes of thanks to those who had been good enough to entertain them. As their President he proposed to move the following resolutions:—

“Resolved, that the best thanks of the Institute be and are hereby tendered to the following gentlemen, public bodies and firms whose kindness has contributed so greatly to the success of the Glasgow Meeting of the Institute:—

- (1) The Right Honourable The Lord Provost and the Corporation of Glasgow for their cordial welcome to the City, and for their great hospitality;
- (2) To the Principal of the University of Glasgow and the authorities thereof for their kindness in placing this hall and the rooms at the disposal of the Institute;
- (3) The Committee and Staff of the Technical College for their kindness in granting facilities to members of the Institute to inspect the buildings and educational equipment;
- (4) The members of the Ladies' Committee for the excellent arrangements for the entertainment of ladies accompanying members;
- (5) Those firms of the Glasgow district who have so kindly granted permission to the members of the Institute to visit their works, viz.:—Argyll Motors Ltd., J. Brown & Co. Ltd., The Fairfield Shipbuilding Co. Ltd., G. & J. Weir.
- (6) To the Chairman (Professor Barr), the Honorary Secretary (Dr. Desch), and the members of the Local Reception Committee to whom the Institute is indebted for the well-considered and completely successful arrangements made for the visit to Glasgow.”

The PRESIDENT said he did not propose to ask anybody to second that resolution. He felt that the best seconding would be from the whole of them. They all felt very deeply the kindness, courtesy, and attention they had received from every one during their visit to Glasgow, and they would carry away a sense of gratitude for the great kindness received during their visit.

The resolution was carried by acclamation.

Professor BARR said the acknowledgment would have fallen better from Professor Gray, who should in the first instance have returned his thanks because they had the privilege of meeting in his room. The recognition on the part of the University would have come more fittingly from him, but on behalf of the University he could say that they were always proud and willing to have meetings of that kind held in their midst. They hoped that when the Institute of Metals visited Glasgow again, they would be in a position to offer like facilities to those offered on that occasion. He could not presume to reply for the Lord Provost and Corporation of Glasgow; but he thought the vote of thanks to them, which no doubt would be forwarded by the Secretary, would simply second what the Institute were good enough to say on the previous evening in recognition of the hospitality received. The Ladies' Committee had, he thought, done useful work, but it was rather unfortunate that it was not formed at a much earlier stage, so that ladies before they came to Glasgow should have had the advantage of knowing what would be done for their convenience while in Glasgow. But he thought, in spite of that, the Committee had done some good. He was certain that the services of the ladies were heartily given to their work. With regard to the Local Committee, he could say for himself that the work had not been at all of an onerous, difficult, or extensive kind. The reason for that, he had not the slightest doubt, was that Dr. Desch had done so much of the work in the background. They in the Committee had not realised its magnitude. For his own part he thanked them for their expression of their appreciation, and he was very glad to know that they had had a successful meeting in Glasgow.

Sir WILLIAM WHITE said before they parted there was one thing which he was sure they would wish to be done: that was, to return their best thanks to the President for the admirable manner in which he had conducted the proceedings of the meeting. On the previous evening he had said what he sincerely felt, and what they all felt. They agreed that there could be no more worthy occupant of the presidential

chair than one who bore the name of Muntz, and in addition possessed the kindly courtesy and high personal qualities which belonged to Sir Gerard Muntz. He need not enlarge on that topic. Many of them knew Sir Gerard better than himself. But he asked them, before they separated, to give him their heartiest thanks for the manner in which he had conducted those proceedings.

Professor TURNER said he had much pleasure in seconding, although there was really no need for a seconder.

The resolution was put by Sir WILLIAM WHITE and carried by acclamation.

The PRESIDENT, in replying, said he thanked them for that kind vote of thanks. He could assure them that that was not really work to him. It was a matter of pleasure, and of the greatest pleasure, and the greatest satisfaction to come there, and to be honoured by being placed in the chair as President of that meeting. He found his own interest in the work of the Institute increasing, and he found great satisfaction in seeing one good paper and discussion follow another.

The proceedings then terminated.

VISITS AND EXCURSIONS AT THE GLASGOW MEETING.

THE arrangements in connection with the Glasgow Meeting were in the hands of a Committee representing the members of the Institute resident in Glasgow and district. This Committee consisted of the following gentlemen:—

**Chairman*—Professor A. BARR.

Professor T. HUDSON BEARE.	H. H. A. GREER.
*Dr. G. T. BEILBY.	*G. H. GULLIVER.
T. BELL.	*W. H. KIDSTON.
Professor J. H. BILES.	J. G. KINCAID.
W. BOW.	*H. A. MAVOR.
*J. BROADFOOT.	W. W. MAY.
W. R. BROADFOOT.	Dr. R. MOORE.
*A. CAMPION.	J. S. GLEN PRIMROSE.
W. M. CRAWFORD.	Commander H. C. RUSH.
J. DENNY.	A. E. STEPHEN.
D. J. DUNLOP.	*J. STEVEN.
Professor J. FERGUSON.	W. WEIR.
A. GRACIE.	

Local Honorary Secretary—*Dr. C. H. DESCH.

**Member of Executive Committee.*

The office of the Secretary and the Local Honorary Secretary was temporarily located in the Natural Philosophy Building of the University of Glasgow.

September 21.

The morning of Wednesday, September 21, was devoted to the reading and discussion of Papers by the following authors:—Mr. A. D. Ross; Messrs. G. D. Bengough and O. F. Hudson; Mr. D. Ewen and Professor Turner.

In the afternoon visits were paid to the works of Messrs. J. Brown and Co., Clydebank, and Messrs. G. & J. Weir, Cathcart. (See pages 62 and 65.)

In the evening there was a Reception by the Right Hon. the Lord Provost and the Corporation of Glasgow at the Council House, George Square. During the course of the proceedings the Lord Provost,

The Right Hon. A. McINNES SHAW, said that in receiving the members of the Institute of Metals they welcomed an organisation which, during its short existence, had already exercised a far-reaching influence upon an important department of their national economy. Nowhere could the Society more appropriately meet than in that city where the science of metallurgy found exemplification in such a variety of directions. As

a mining centre the West of Scotland had been the nursing ground for many great organisations, and had fostered and encouraged the genius of many distinguished men. The union of science and practical experience must always be productive of the best results, and the industrial supremacy of the British Empire depended upon the degree in which their students and experts realised the service which scientific collaboration with the practical and obvious application of the principles of manufacture was fitted to render. The important results which followed the formation of the Iron and Steel Institute in 1869 in regard to iron and its alloys led to the feeling that a similar organisation in reference to other branches of metallurgy would be of equal value, and that Institute since it was established in 1908 had amply justified the step then taken. Among the active promoters of the Institute were to be found many representatives of the users of metals in almost every branch of engineering and manufacture, and not a few distinguished members of other technical institutions. Its value had been recognised in the highest scientific quarters, and he felt sure that it was destined to hold an honourable place for many years among the scientific institutions of the country. They lived in an age of specialisation, and if they were to get the best results in any particular direction of scientific and practical inquiry, they must see that the fruits of industrial energy and research were made available to the common knowledge of the nation. The Institute of Metals, therefore, had been established to form a means of communication between members of the non-ferrous metal trades upon matters bearing upon their respective manufactures, and to advance the knowledge of metals and their alloys. Britain must maintain her supremacy in the competition with other nations, and the existence of such institutions as the Institute of Metals was the best hostage for the future progress and development of their industrial and commercial enterprise. It was therefore not in any merely conventional terms that he welcomed the members there that night on behalf of the Corporation of the City of Glasgow. They were particularly pleased to have with them the President, Sir Gerard Muntz, a gentleman whose name was synonymous with all that was progressive and enlightened in the science of metallurgy. He had the greatest possible pleasure in welcoming Sir Gerard and the members.

Sir GERARD MUNTZ, replying to the welcome, said that when he came to Glasgow as President of the Institute, he looked forward to the visit with much pleasure, and anticipated that in that great city they would meet many gentlemen interested in their investigations. He knew from past experience that amongst the many great undertakings for which the city was celebrated, they would see very much to interest them in the way of manufacture, and they knew also they might anticipate a thoroughly hospitable welcome. He could assure them, and he thought he could speak also on behalf of his fellow-members, that the greeting they had received had been far in excess of anything they anticipated. He had to thank the Lord Provost for the very handsome way in which

the Corporation were entertaining them in those beautiful rooms, and for the eulogistic way in which he had introduced the subject of the new Institute. He described it as a new Institute because they were the youngest of all the institutes. The Lord Provost had been good enough to tell them what had been done up to the present. Thanks to his predecessor, Sir William White, they had done something. Sir William launched the Institute, and gave it its first impetus, and so far they had done quite as much as could be expected. Up to now they had been very much beginners. They were making a start in a field of research which was so wide that it was almost alarming to contemplate. That reception which they were receiving at the hands of the Lord Provost would encourage them to realise that that Institute might be of greater importance possibly than some of them had hitherto anticipated, because when they felt that a real interest was taken in their work it encouraged those interested in the welfare of the Institute to put their shoulders to the wheel and do the best they could to push things forward. They had that day been received most kindly by the city's great University, who had placed their hall at the disposal of the Institute. They had met that day in the historical venue of the University, a place whose name was largely associated with scientific work, and they had seen also the Technical School, where they had been kindly entertained and shown round the building. Many of them had had opportunities of inspecting the plant and arrangements. He had seen various technical schools and plants throughout the country and elsewhere, and he was glad to be able to say that he had never seen anything equal to what Glasgow had been able to show them that day. He was told by one of the staff that the city was proud of its Technical Institute, and he (Sir Gerard) could say that it had reason to be proud. He looked upon institutes of that kind, and universities such as they had in Glasgow, and such as they had also in his own city of Birmingham, and as were to be found in many of the great leading cities of the country, as schools for their Institute, because it was to the technical schools and the universities that they were looking for the younger men to come forward with all the advantages of modern education which were to be had in these days. They looked to them to push forward in the pursuit of knowledge which was engaging the labours of the Institute, and in regard to which they felt that they had only just begun. He thanked the Lord Provost and the city for the kindness of their reception.

SIR WILLIAM WHITE said that he was that evening assuming the character of an extinct volcano and making an unexpected eruption. Until he came to the City Hall he was not aware that he was to say anything. Therefore, what he had to say would be spontaneous, and not one of those well-considered impromptus that took a fortnight to prepare. He heartily endorsed everything Sir Gerard Muntz had said as to the gratitude which members of the Institute of Metals felt to the Lord Provost and his colleagues of the City Council, as well as to the University and the citizens of Glasgow, for that splendid reception. The Insti-

tute was young, and had probably all the faults of youth as well as some of the virtues. Personally, he was no longer young, as doubtless they had observed, but his sympathies were with the young, and he had not got too old to forget that during a large part of his career he was thought to be too young for the places he filled. He always felt he must do his best to help on the younger members in any enterprise, and he supposed that feeling had something to do with his finding himself first President of the Institute of Metals. The Institute of Metals in its constitution furnished a fresh illustration of the truth of an old saying in a very old book about the virtues of the triple cord that could not easily be broken. It had been founded to bring together the makers of metals and the users of non-ferrous metals as well as the scientific men upon whose research work they must depend so largely for future progress in many important directions. It was quite true that the present was an age of steel, but they would get on very badly if they had not the non-ferrous metals, and especially gold and silver. That Institute, at all events, dealt in gold and silver—of course in a strictly academic fashion; and its resources were very modest, as any one could see who looked at its balance-sheet. In his experience of life he had found that the largest means were not always productive of the greatest results. At all events, they could claim for the Institute of Metals that it spent every penny in the canny Scotch fashion and tried to get the most out of it. In regard to non-ferrous metals, for those he had named and many more with which they were acquainted, the range of research was very great. The attention that had been given to the scientific side of metallurgy up to the time the Institute was founded had certainly not been commensurate with the importance of the subject. He was not in the least belittling the admirable work that had been done by individual workers. But there was no corporate body dealing with those matters in this country, or indeed, so far as he knew, in any other country. It was left to citizens of this decadent island to lead the way in that direction. Of course, they were accustomed to be lectured every day by the halfpenny papers on the evil ways into which they had fallen, were assured that they were going downhill with a highly accelerated movement and warned that there could be only one result. In Glasgow they did not believe those assertions, and Great Britain did not believe them. He had read nothing for a long time which gave him so much pleasure as the way in which some of the colonial journalists who had been over to take part with their Canadian brethren in military manoeuvres had spoken on this subject. They said: "We shall go back to Canada and tell the friends there that all this talk that we have heard of the falling back of England among the nations is ridiculous nonsense." That was good hearing. There was only one regret he had in connection with his Presidency of the Institute, although no one was more delighted than himself to see Sir Gerard Muntz take the chair. His regret was that they did not come to Glasgow while he was President. They talked of coming there last year. But it was not quite convenient, and now they were there under the guidance of a gentleman whose family name as well

as his personal qualities made him an ideal occupant of the chair. They had other names of eminent manufacturers of metals on their list, including Sir Henry Wiggin, who was sitting beside him, and who himself represented a great metal industry. There were others on that platform well representing the three branches, namely, the makers of metals, the users of metals, and the science of metals. That represented the threefold cord of which he had spoken. So long as that was untwisted, so long he was sure the Institute of Metals would flourish and continue to be a body whom the Lord Provost and his fellow-citizens would always be proud to welcome to Glasgow.

The LORD PROVOST said they were honoured with the presence of Sir Donald MacAlister, the Principal of the University, and he had very much pleasure in asking Sir Donald to speak to them.

Principal Sir DONALD MACALISTER said that if Sir William White was justified in calling himself an extinct volcano, who had been called upon to re-erupt, his own position was much more serious. Sir William only arrived that afternoon, and therefore had not had to talk earlier in the day. He (Sir Donald) had already been called upon that morning to address them at the University, and it was not until he entered the room that he was informed that he would be called upon to speak again. He felt not at all like a volcano (he could not admit that Sir William White was in any sense extinct) that was called upon for a fresh eruption, but rather like a squib that had gone off once, and as they knew it was not very much use putting the match to that squib again. At the same time he was glad to have the opportunity of saying to a wider audience than was assembled at the University how heartily they welcomed the Institute of Metals, and how ready they were to give them such hospitality as they were able to give in connection with their serious work. The Corporation and the University were always anxious to co-operate in all good work that would bring credit to Glasgow, and send visitors to Glasgow away with a proper impression of its importance. In this case he thought the division of labour between the Corporation and the University had been most fit and proper. The Institute had gone to the University to work, and they had come to the Corporation to play. As there was to be within those walls the customary entertainment provided by the City Council, members of the Corporation would not think it necessary that he should further refer to its powers of providing agreeable pastime for hours of relaxation. Every one invited there would feel that the Corporation entertained its guests in a way which was most handsome and hospitable. In Glasgow they never hesitated to welcome an assembly of scientific and practical men like the Institute of Metals, because they felt they had something to show them worthy of their attention, and calculated to defy their criticism in any unfavourable sense. They did not feel any anxiety as to what might arise from their visit to Glasgow, notwithstanding the example of an Eastern ruler named Hezekiah, who invited strangers from Babylon to

look at his non-ferrous metals, "his precious things, the silver and the gold," with disastrous results. They said to the Institute of Metals: "Come to us. We are doing research in metallurgy at the University, and research in metallurgy at the Technical College, and by the practical application of the knowledge gained in both these institutions we are doing our best for the progress of many a manufacturing and industrial enterprise in Glasgow." They could go back, even to Birmingham, and say that they had seen in the West of Scotland something worth seeing. For that reason they were always ready to invite to Glasgow those who in any department of knowledge, pure or applied, had attained distinction at a distance. They were sure to take away from Glasgow a proper appreciation of what the citizens were doing there. They at the University were very glad to have the opportunity of showing themselves as fellow-workers with their distinguished visitors.

Professor BARR said if any one in the room was inclined to doubt the word of Sir William White or of Sir Donald MacAlister, he was ready to corroborate what they had said. He had no notice whatever that he was to speak on that occasion. But being there as representing the Local Committee who had asked the Institute of Metals to come to Glasgow, it was his first and most obvious duty, and one which he discharged with the greatest pleasure, to thank the Lord Provost and Corporation of Glasgow for so kindly inviting them to their splendid rooms and giving them an entertainment which he was sure was greatly appreciated. Their first and greatest concern in bringing the visitors to Glasgow was of course to arrange that the weather conditions would be suitable for their reception. If they were inclined to criticise their work in other respects, he thought they would at least give them credit for having done something really good in that matter. They were looking forward to the presence of the visitors at an excursion on the Clyde on Friday, and he hoped the weather they were now having would continue until then. But he thought he might say, what he had occasion to say earlier to some of their members, that if the weather did not appear in the morning to be favourable, he should advise them not to take that as a sample of what they might expect later in the day. On two previous occasions of a similar character he could recollect going down the Clyde in a perfect downpour of rain, and having such a view of Arran when the clouds rolled off as he had never had before, and as they would not have had if they had started under the most brilliant skies.

After referring to arrangements made for the entertainment of the ladies at the Grand Hotel, and for visits to works, Professor Barr said he hoped those opportunities would be utilised to the fullest extent. In conclusion, he would thank the Lord Provost and the Corporation for their kindness in acceding to the request of the Local Committee and entertaining the members of the Institute that evening.

The LORD PROVOST said he thought they would all admit that the experiment of extemporaneous speaking had been highly satisfactory.

60 *Visits and Excursions at the Glasgow Meeting*

He was unable to say that he did not get any notice. As a matter of fact, he did get notice. He was inclined to think that in future they would follow the example that had been set that evening. On behalf of the Corporation they offered their sincere thanks for the kind words of Professor Barr. They also thanked the other ladies and gentlemen who had so warmly endorsed the words that had been spoken—he would not say with loud applause, because they did not expect ladies with gloves to make a very loud noise. He took it they were pleased to be there, and the Corporation were deeply grateful that they had come. Professor Barr was a very lucky man. It so happened that he was Chairman of the Aviation Meeting during the month of August, and that was the only good week as regards weather they had. He hoped his good luck would continue, and that the ladies and gentlemen who were honouring Glasgow by their visit would find the citizens desirous of showing them everything they could and treating them as hospitably as possible.

September 22.

The morning of the second day of the Glasgow Meeting (Thursday, September 22) was devoted to the reading and discussion of Papers by the following authors:—Mr. F. Johnson; Dr. C. H. Desch; Mr. H. S. Primrose.

In the afternoon visits were paid to the works of the Fairfield Ship-building Co., Govan; Argylls Ltd., Alexandria; and the North British Locomotive Co., Hyde Park, Springburn. Visits were also paid to the buildings of the Glasgow and West of Scotland Technical College, and an inspection was made of certain of the buildings of the University. (See pages 60 to 67.)

September 23.

On Friday, September 23, there took place an all-day trip on the Clyde, a specially chartered steamer visiting the Kyles of Bute and the Isle of Arran.

VISITS TO WORKS, &c.

September 21 and 22, 1910.

ARGYLLS LTD.

The machine shop, which is the largest of the manufacturing departments, covers $4\frac{3}{4}$ acres of ground, also accommodates the engine-building department, extending the full length of the side of the shop. It is here that the Argyll engine, the machined parts having been received through the stores from the various departments, are put together, and afterwards run on the testing stands. Immediately to the north is the grinding department, and beyond this is a large and extremely interest-

ing collection of machine tools. These machine tools have been brought together from the best manufacturing firms at home and abroad, a number being of American and German origin, and the others from different places in Britain. Power to drive the machinery in this department is furnished by gas engines and electric motors to an aggregate of 600 horse-power.

The assembling shop, which measures about 400 feet by 66 feet, is entirely devoted to the assembling of components. Here are built up steering gears, front and rear axles, gear boxes, &c.; gear boxes and back axles can also be seen on test in this department previous to their being delivered to the stores to be ready for erection in chassis.

In the power house, which is a separate building, there are installed seven 4-cylinder vertical type gas engines, coupled to direct-current generators, which supply electricity for lighting, and, where necessary, driving machinery in the various shops.

Beyond the power house are two Babcock & Wilcox boilers, supplying steam for heating purposes throughout the shops in the works.

In the same block as the power house and boiler house, but separated by a wall, is the smithy, this having in its peculiar way its own claims for attention. All the smiths' fires are fitted with smoke-exhausting hoods, and by this means the atmosphere is kept comparatively clear. Farther down the building is the case-hardening department, and at the end the tinsmiths', brazing, buffing, plating, and sheet metal department.

The building in which the bodies are painted, upholstered, and varnished measures 422 feet in length, by 65 feet in width, and 20 feet in height at the eaves, rising to 33 feet at the peak of the roof. The bodies are brought from the coach-building shop next door, are mounted on special stands, and are treated to between twenty and thirty coats of paint.

The bodies having been painted, are passed into the trimming department for upholstering, and are afterwards sent into another department for varnishing.

The varnishing room is the only department of the factory which visitors are not invited to enter; the obvious reason for the restriction being the necessity of limiting traffic at all times in order to keep out dust.

The coach-building department is the same length as the combined painting, trimming, and varnishing departments, but it is 35 feet wider. All the wood-working machines, which are electrically driven from motors erected on the roof girders, are placed down the middle of the top portion of the shop. The space occupied by body-builders alone is sufficient to allow of 100 bodies being built simultaneously.

The chassis shop or erecting department is in some ways the most noteworthy section of the establishment. Constructionally it is the highest in the roof, is equipped with a couple of electric cranes, and has a railway siding of its own, which allows of cars being loaded indoors into trucks and despatched to any quarter. This shop measures 390 feet by 80 feet.

One of the most important departments is the store. It extends a distance of 540 feet underneath the office buildings, and contains thousands of pounds worth of iron, steel, aluminium, brass, indiarubber, glass, &c. Here may be seen huge bars and tubes of steel, brass and phosphor bronze, hundreds of pneumatic tyres, large quantities of accumulators, lamps and various other fittings that are not usually made by car manufacturers.

The gas plant is a very important part of the equipment of the works. It produces the gas not only for the engine driving the machinery in the vast machine shop, but also for the engines in the power house which generate all the electric light and power used throughout the works. The present installation consists of eight units of 200 horse-power maximum capacity each.

Near by the suction gas plant stands the foundry, which within the last six months has been extended to cope with the increased working of this department. Cylinders, gear boxes, axle casing, and a hundred and one other different parts are cast here; and as time goes on further extensions will have to be made to enable the parts to be turned out as fast as they are required.

JOHN BROWN & CO. LTD., CLYDEBANK SHIPBUILDING AND ENGINEERING WORKS.

The Clydebank shipbuilding yard, established in 1873, is one of the most perfectly equipped in the world. The output in a single year has amounted to 90,000 tons of shipping and 108,000 horse-power of machinery. The vessels built here have included a large number of warships for the British and several foreign navies, the armour-plates being supplied from the firm's steel-works in Sheffield. The yard has also a great reputation for torpedo vessels. Some of the fastest merchant vessels have been built at Clydebank, including the famous Cunarder *Lusitania*. The very high speeds now attained have been made possible by the introduction of steam turbines, in the development of which the company has taken a prominent part, and special machinery is in use for the construction of the large drums, &c., required.

Clydebank has nine building berths, on which ships 800 feet long may be built. The fitting-out basin is equipped with two large cranes capable of lifting 150 tons, and a number of smaller cranes.

An important feature of the works is the experimental tank, one of the two owned by shipbuilding firms in this country. This tank has proved very useful in designing various vessels for which the company is responsible.

THE FAIRFIELD SHIPBUILDING AND ENGINEERING WORKS, GOVAN.

These famous works are situated three miles to the west of Glasgow, on the south bank of the Clyde, and occupy an area of eighty-five acres. The firm was originally founded in 1834, when it occupied a single

engineering shop with a 3 horse-power engine. Shipbuilding was commenced in 1860, and the present works were laid out in 1864. The work done includes shipbuilding of every kind, and the construction of marine engines (both of the reciprocating and the turbine type) and boilers. The company also, as part owners of armour-plate works at Sheffield and of ordnance works at Coventry, is able to build the hull of a warship, construct the whole of the machinery, armour the ship, and supply the guns and their mountings. From 1870 to 1909, the firm has built fifty-five vessels of war and supplied the machinery for twelve others, the aggregate value of this fleet being nearly £18,000,000. The yard also has a high reputation for the construction of passenger liners, cross-channel boats and steam yachts, no less than twenty-eight mail-steamers for the Atlantic service having been built within the last thirty years.

The shipyard is fully equipped with machinery for dealing with the largest sizes of plates and beams. About 250 tons of steelwork have been put in place in one week, and in some cases over 80 tons in one day, on a vessel on the building berth. In addition to the great steel-working shops, there are very extensive wood-working departments, the whole of the joiner's work, and even the manufacture of the furniture for passenger liners, being carried out on the premises.

The fitting-out basin covers more than five acres, and has an entrance 270 feet wide. The depth of water is 29 feet at low tide. It is provided with shear-legs capable of lifting 130 tons, and several cranes, of which the largest can lift 20 tons at a radius of 30 feet, or 9 tons at a radius of 60 feet.

The most striking features of the engine works are the arrangements for the construction of large steam turbines. Turbine casings up to 30 feet long and 12 feet wide, and rotors up to 50 feet long and 15 feet in diameter, can be taken. One of the vertical and horizontal planing machines is capable of taking a surface up to 24 feet by 19 feet.

Turning to the non-ferrous metals (which also find application in turbine work in the form of the bronze turbine blades), a large shop is devoted to galvanising by the electric process, the weekly output being 1200 to 1300 tubes, from 1 to 3 inches in diameter. The brass-foundry has 20 pot furnaces, and two large furnaces of 16 tons and 8 tons respectively. The output of this foundry is 60 to 70 tons per week, and castings up to 20 tons can be made. The castings are dressed by pneumatic tools.

The electric power station supplies both the shipyard and engine works, and is equipped with seven generating sets, having a total capacity of 2630 kilowatts. The steam is supplied by seven water-tube boilers, whilst two marine cylindrical boilers supply steam for hammers, hydraulic pumping machinery, &c.

NORTH BRITISH LOCOMOTIVE CO. LTD., HYDE PARK WORKS,
GLASGOW.

The *Administration Building* is situated in Flemington Street, Springburn. In addition to the usual accommodation for the directors

and secretaries, it also houses the entire commercial staff, buying, costing, shipping, &c., and the technical and drawing department.

The *Works*, which consist of three fully-equipped and independent units, are "Hyde Park Works," formerly Neilson, Reid & Co.; "Atlas Works," formerly Sharp, Stewart & Co., both situated in Springburn; and "Queen's Park Works," formerly Dubs & Co., situated in Polmadie.

The combined output is now over 19,000 engines, and the present capacity per annum is about 700 main line engines of the highest grade of workmanship and material.

The *Hyde Park Works*, to which on this occasion a visit was made, are in direct connection with the North British Railway Company's line.

General Survey of the Works.

North Side.—Joiner and pattern-making shops, pattern stores, and the brass and iron foundries with cupolas, core-drying stoves, &c. These shops are detached from, but convenient to, the main group of shops.

Centre, North to South.—Template shop, cab shop, boiler-mounting shop, boiler shop, smithy and forge in one general group.

Western Side.—Wheel and fitting shops, machine shops (presently in course of reconstruction), finishing shop, and light turning and tool-grinding shop.

Between these Two Main Groups.—Power stations, including boiler-house, electric power-house, and pneumatic power-house.

East End.—Heavy tool-shop, paint shop and material store. Near these are the tender and tank shops and the cylinder shop. Although these are situated at some distance from the engine-erecting shops they are in direct communication by rail and overhead cranes.

The respective shops have their overhead travelling or walking jib cranes, of powers varying from 90 tons to 5 tons, all of which are electrically driven. The steam pressure throughout is about 200 lbs. per square inch, except in the forge, where it is reduced to 65 lbs.

The electric current is "continuous" and 250 volts, the hydraulic pressure is 1500 lbs. per square inch.

WILLIAM ROSS & SONS, 27 THISTLE STREET, GLASGOW.

This is a small foundry, dealing with a considerable variety of alloys. The visitors were shown Ross's method of dealing with fumes in casting brass and manganese bronze. The crucible is covered with a plain cover just before pulling, and is then placed under a sheet-iron hood, with uptake. After skimming, the cover is replaced by a patent pouring cover, which is not removed until after the crucible has cooled under the hood. The escape of fumes into the foundry is thus almost completely prevented.

The firm manufactures steam fittings and laundry and sanitary appliances.

G. & J. WEIR LTD., ENGINEERS, CATHCART.

The works of Messrs. G. & J. Weir Ltd., Cathcart, are devoted chiefly to the manufacture of the firm's specialities in marine auxiliary machinery, comprising direct-acting feed pumps, service pumps, independent air pumps, marine evaporating and distilling plants, feed water heaters, &c.

Every navy of importance has been supplied with Weir equipments, so that the character and quality of the firm's products are of the highest grade, as an inspection of their establishment indicates.

The works cover thirteen acres, and are laid out on the most modern lines, comprising pattern shop, iron foundry, brass foundry, smithy, copper shop, machine, and erecting shops complete.

The iron foundry is a steel structure 270 feet long by 210 feet broad, with two Thwaites cupolas with blast furnished by Root's blowers. The three main bays are served by four electric cranes, while the central floor is served by six hydraulic cranes for closing boxes, &c. The brass foundry is furnished with seventeen crucible furnaces and two reverberatory furnaces, and has a large sand-blasting plant for cleaning castings. Both foundries are furnished with large stove accommodation for drying complete moulds. A laboratory and a testing department, as an adjunct to the foundries, check and supervise their products.

The main machine shop consists of ten bays, 330 feet long, and is equipped with the latest and most up-to-date plant by British, American, and Continental manufacturers. It is driven by gas-engines working on suction gas and partly by electric current supplied by the Clyde Valley Electric Power Company, and has departmental divisions under stores, tool room, gauge department, &c.

The erecting, water-testing, and steam-testing shop consists of four bays, 375 feet long, equipped with electric travellers, and at the steam-testing platform with hydraulic jib cranes.

The small pump department is a reproduction in little of the large shops with special automatic department for the production of duplicate parts in quantity.

Standardisation is one of the features of the establishment, and interchangeability is secured by regular inspection system.

Commercial and drawing offices complete the establishment, which is, in point of equipment, system, and organisation, one of the most advanced and interesting in the country.

THE UNIVERSITY.

The present handsome pile of buildings on Gilmorehill, in which the University of Glasgow is housed, was erected from the designs of the late Sir Gilbert Scott, and was opened in 1870, replacing the old buildings, dating from the fifteenth century, in the centre of the town.

The main buildings are Gothic in design, and the lofty tower is a

conspicuous feature of Glasgow. The Bute Hall, which is used for graduations and other academic ceremonies, occupies a position between the two principal quadrangles. The scientific departments having outgrown their accommodation, additional buildings have been provided from time to time. The Natural Philosophy Buildings, in which the meetings of the Institute were held, were completed in 1907, and comprise a large and well-fitted lecture theatre, physical laboratories, and small rooms for special research purposes. The collection of apparatus includes many objects of historical interest. There is a full equipment for the production of liquid air and liquid hydrogen.

The senior laboratories of the chemical department are at present contained in a temporary building. The metallurgical laboratory occupies the lowest floor of this building, and is equipped with gas, coke, and electric furnaces, and with the necessary appliances for metallurgical analysis. Two rooms on the top floor are devoted to metallography, and are provided with a very complete photomicrographic equipment.

The buildings of the engineering department were erected by the university with funds drawn from the Randolph Bequest, and equipped by contributions in money and kind by engineers and others interested in the advancement of applied science. The total cost was over £40,000. They were opened by Lord Kelvin in 1901.

The buildings include various laboratories, boiler room, drawing classroom, lecture theatres, library, and reading room. The equipment of the main laboratory includes various machines for the testing of materials, the chief of which is a 100-ton horizontal testing machine by J. Buckton & Co. of Leeds. This machine may be used for testing materials in tension, compression, bending, shear, and torsion. There are also a 10-ton vertical testing machine for tension, compression, and bending tests, a torsion machine, and wire-testing machines of special design. These machines are all arranged to give autographic stress-strain diagrams, while small strains are measured by extensometer or compressometer.

The steam plant includes a boiler capable of raising 2500 lbs. of steam per hour, a 50 horse-power compound steam engine, and a 50 horse-power Delavel steam turbine, both coupled to dynamos, and a refrigerating plant. There are also gas, oil, petrol, and hot air engines, all arranged for experimental work.

The electrical laboratory contains various types of continuous and alternating current generators, all motor driven; a tramway motor set, and other electric motors arranged either for direct experimental use or coupled to a pump, fan, hoist, &c. The laboratory is fully equipped with separate accumulators for low voltages, and with 100 volt and 250 volt batteries. The instrument room is equipped with the most modern measuring instruments.

In the hydraulic laboratory provision is made for the very accurate measurement of the flow of water over weirs and for the accurate testing of the various hydraulic motors, including an inward flow turbine, Pelton wheels, and a reaction turbine. The equipment also includes a motor-

driven centrifugal pump; venturi and vortex meters; apparatus for experimenting on the flow of water through pipes and orifices; and for studying the action of water in forming river bends.

THE GLASGOW AND WEST OF SCOTLAND TECHNICAL COLLEGE.

This college was established in 1886, as the result of the amalgamation of several older institutions, one of which was Anderson's College, founded in 1796, and the first technical college in the kingdom. The first section of the present building was opened in 1905, and the last section has been completed this year. The whole has cost over £400,000, and forms the largest building in the kingdom devoted to education.

The equipment of the engineering laboratories includes a horizontal testing machine of 100 tons capacity, taking specimens up to 12 feet long in tension and beams 15 feet long; a vertical testing machine of 12,000 lbs. capacity, and many special forms of testing machines. The experimental plant includes a large horizontal steam-engine, a motor-car testing plant, a Diesel oil engine, a gas engine with suction producer, &c., as well as a variety of electric generators and motors.

The metallurgical department is situated on the third floor of the building, and comprises furnace room, general laboratory for analytical work, room for pyrometry and metallography, store rooms, lecture rooms, lecture preparation room, and rooms for polishing and preparation of samples, and electro-chemical work. The equipment is at present being considerably extended, especially as regards apparatus for experiments on the melting, casting, and treatment of metals and alloys, also for the testing of ores to determine suitability for treatment by various processes.

The laboratories are provided with necessary apparatus for metallurgical analysis and experiment, including wind furnace, gas and coke muffle furnaces, electric tube furnaces for experimental work, and a large Richmond gas-fired furnace for experiments on heat treatment of metals and alloys and other purposes. There is also a Whiting cupola capable of melting 1 ton per hour; a tilting crucible melting furnace of the M.R.V. type, specially designed for the production of the highest temperatures. Moulding boxes and tools, ladles, and the usual necessary accessories are also provided. Pyrometers of the portable thermo-couple type are in use for ordinary temperature control, and also a recording pyrometer of the Armour type. There is in addition a complete installation of potentiometers, galvanometers, &c., for thermal investigations. In the metallography room are a number of microscopes, specially arranged for the examination of metallic sections. There is also a Zeiss-Martens microscope outfit, complete with electric lamp, optical bench, and a large Zeiss camera arranged for photographic work at the highest powers.

ON MAGNETIC ALLOYS FORMED FROM NON-MAGNETIC MATERIALS.

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SINCE early times it has been customary to divide the elements into the two classes "magnetic" and "non-magnetic." The former class includes iron, nickel, and cobalt, the three simple metals which exhibit in a marked degree the well-known phenomena of magnetic attraction and repulsion, and of permanent or residual magnetism. The other elements are generally grouped in the "non-magnetic" class. Many of them, however, are not non-magnetic in the strict sense of the term. Under the action of powerful magnetising forces they exhibit polarity, as do iron, nickel, and cobalt, although the magnetism so induced in them is relatively very small. This magnetism, too, is entirely, or almost entirely, temporary, vanishing on the removal of the magnetising force. Materials which show such phenomena are more accurately described as "para-magnetic" than as "non-magnetic," and it is convenient to employ the special term "ferro-magnetic" for iron, steel, nickel, cobalt, and other materials which are highly magnetic and retentive.

Of great interest in the study of magnetism are the effects produced by alloying or admixing different elements. Many of those alloys have resultant properties which give them important commercial applications. Thus chrome and tungsten steels, on account of their great retentivity, are specially suited for the preparation of permanent magnets. Again, the addition of such elements as silicon or aluminium to iron results in certain cases in increased susceptibility to magnetisation and reduced hysteresis loss, thus rendering the material well adapted for transformer working. From the theoretical point of view, of still greater importance was the discovery that by alloying together the two ferro-magnetic elements, nickel and iron, in the proportion of one part of the former to

three of the latter, a non-magnetic or merely para-magnetic material was produced.*

The reverse phenomenon, viz. the production of a decidedly ferro-magnetic material by the alloying of non-magnetic or para-magnetic elements, was unknown until 1903, when Heusler announced his discovery that certain binary and ternary manganese alloys showed considerable ferro-magnetism.† The binary groups found to have magnetic properties were Mn + Al, Mn + As, Mn + B, Mn + Bi, Mn + Sb, and Mn + Sn. These retain their magnetic properties when copper is added, and in some cases the ternary alloy is much more strongly magnetic than the binary material. Of all these alloys the most remarkable are the 'copper-manganese-aluminium group, commonly referred to as the Heusler alloys. Certain members of this class are very susceptible of magnetism, and have a saturation intensity of magnetisation equal to about 80 per cent. of that for pure nickel. In low fields they are as permeable as cast iron.

The copper-manganese-aluminium alloys have been investigated by several experimenters, and a large amount of interesting data has been published regarding their magnetic properties.‡ No results, however, have been given of tests on the other ternary systems, with the exception of a brief note on the copper-manganese-tin alloys in Heusler's original paper.

Since 1905 the author has conducted research in the Physical Institute of the University of Glasgow on these ternary magnetic alloys. The earlier work consisted in a detailed examination of the properties of one of the most highly magnetic of the copper-manganese-aluminium series, and in particular of the effects produced by varying thermal treatment. This work was afterwards extended to different

* J. Hopkinson, *Proceedings of the Royal Society*, 1889, vol. xlvii. p. 23, and 1890 vol. xlviii. p. 1.

† F. Heusler, *Verhandlungen der Deutschen Physikalischen Gesellschaft*, 1903, vol. v. p. 219.

‡ See several papers in the *Verhandlungen der Deutschen Physikalischen Gesellschaft*, *Proceedings of the Royal Society*, *Proceedings of the Royal Society of Edinburgh*, *Proceedings of the Royal Philosophical Society of Glasgow*, *Zeitschrift für anorganische Chemie*, *Schriften der Gesellschaft zur Beförderung der gesamten Naturwissenschaften zu Marburg*.

members of the same ternary system, and more recently investigations have been made on other ternary groups and on certain binary systems. The binary groups, however, have been examined only in so far as it was thought probable that they might throw light on the more complex phenomena of the ternary alloys. It is proposed to give in this paper a general account of the results which have been obtained in these investigations.

SCOPE OF THE RESEARCH.

Magnetic tests have been carried out on alloys belonging to the following ternary systems:—

- (1) Copper-manganese-aluminium.
- (2) Copper-manganese-tin.
- (3) Copper-manganese-antimony.
- (4) Copper-manganese-bismuth.

In the case of the first two systems several members of the group were prepared and tested, so that the effects produced by thermal treatment and their variation with the composition of the alloy might be fully studied. In the two latter cases the object of the tests was merely to compare in a general manner the properties of these systems with the two former. One or two castings accordingly sufficed for the purpose.

The binary groups tested comprised the following:—

- (1) Copper-manganese.
- (2) Copper-aluminium.
- (3) Manganese-antimony.
- (4) Manganese-boron.

The object of these investigations being to ascertain the magnetic properties of the various intermetallic compounds formed, the number of specimens required was again small.

MATERIALS EMPLOYED.

In the preparation of the alloys every endeavour has been made to obtain materials of the highest purity. Electrolytic

copper was used in all cases, and contained less than 0.15 per cent. total impurity. The manganese selected was prepared by the thermite process. It contained about 98.5 per cent. of manganese, the remainder consisting chiefly of silicon, iron, and aluminium. The presence of aluminium in the manganese may possibly have influenced slightly the results obtained in ternary groups other than the copper-manganese-aluminium alloys, as the addition of aluminium to manganese produces a magnetic material. The amount of aluminium introduced in this way was always very small, and the consequent error in the results must therefore be almost or entirely negligible. The iron impurity is of no greater moment, as alloys prepared by the use of ferro-manganese, and hence having a decidedly larger iron content, showed almost identical magnetic properties. The presence of small quantities of silicon has no effect on the magnetic properties except in so far as it reduces the amount of magnetic material in the specimens. The thermite manganese thus contains no objectionable impurity. On the other hand, it possesses a great advantage in that it has a very low carbon content, only a trace of that element being present. This is important, as the presence of carbon has a powerful influence in modifying the equilibria of manganese alloys, and also produces change in the magnetic properties of manganese itself.

PREPARATION OF THE SPECIMENS.

In the preparation of the ternary alloys, the plan adopted was to make first a manganese-copper alloy and then to add the third metal to it. As a rule, the manganese-copper was composed of these elements in the weight ratio of 3:7, that ratio giving the alloy of lowest melting-point in the binary system (about 870° C.). In this way there was little or no loss through volatilisation, &c., on adding the third constituent. On account of the extreme readiness with which hot manganese absorbs carbon, special precautions had to be taken to prevent the admission of this element. In general, therefore, the alloying was conducted in a "Salamander" crucible under a layer of fused barium chloride. Charcoal

cannot safely be employed unless the percentage of manganese present is small. The metal was cast in dry sand moulds lined with whiting. When moist sand was tried, it was found that the material was invariably of somewhat inferior magnetic quality and could not be brought quite up to the standard by annealing or other heat treatment. The alloy was cast vertically in the form of cylindrical rods about 9 inches long and $\frac{7}{16}$ inch in diameter. The binary alloys were prepared in much the same way, except that the majority of them, being too feebly magnetic to test by the usual methods, were cast as small rods measuring about $4\frac{1}{2}$ inches by $\frac{1}{4}$ inch, and were tested between the poles of a powerful electro-magnet. These bars were in all cases sufficiently long to allow a small piece to be cut off the lower end and rejected, and two further portions—one from either end—to be taken for chemical analysis, leaving a rod of suitable dimensions for the magnetic test.

INVESTIGATION OF THE MAGNETIC PROPERTIES.

The programme of the magnetic tests on the ternary alloys was as follows:—

1. To determine the magnetic quality of the alloys in the condition as cast.
2. To find the simplest and most efficient heat treatment for bringing the alloys into a stable condition with the highest possible magnetic quality.
3. To investigate the changes produced in the magnetic properties by exposure of the alloys to different temperatures, and incidentally to determine the critical temperature and investigate the reversibility of the thermal treatment.
4. To examine the effects produced by quenching, annealing, and baking the alloys.

The tests were carried out on a magnetometer specially designed by Dr. J. G. Gray and the author for investigations of this kind.* The main feature of the instrument (Fig. 1) is the simple and novel method introduced for rapidly securing

* J. G. Gray and A. D. Ross, *Proceedings of the Royal Society of Edinburgh*, 1909, vol. xxix. p. 182; *Philosophical Magazine*, July 1909.

accurate compensation of the effects due to the electric current in the magnetising solenoid. The magnetometer proper (A), the solenoid (H), the compensating coils (C_1 , C_2 , C_3), and the lamp (L), for showing the movement of the magnetometer needle, are all mounted on a strong mahogany baseboard, and move freely in channelled beds. They can be firmly fixed by friction clamps. C_1 is the principal compensating coil, C_2 a coil for fine adjustment, while C_3 removes any error due to want of proper alignment of the other coils. When tests were to be carried out at temperatures above normal, the specimens were placed in an electric furnace of the newest type* for use within the magnetising solenoid. In this the alloys could be raised to temperatures approaching their melting point without danger of oxidation ensuing. When in some cases it was desired to maintain specimens for more than a day at a moderately high temperature, the bar was, as an additional precaution, tightly packed with pure kaolin clay in a copper tube inserted in the furnace. The kaolin clay used for this purpose was previously strongly heated and then powdered so as to prevent subsequent shrinkage when used as a protection for the specimens. The measurement of temperature was effected by a platinum, platinum-iridium thermo-element used in conjunction with a millivoltmeter. This apparatus was calibrated before and after the tests by determination of five boiling and freezing points, and was found to have remained unchanged during the interval. While the arrangement was not so sensitive as one involving null methods with the potentiometer or wire-bridge, it was sufficiently accurate for the purpose in view, and was, moreover, preferable on account of its simplicity.

RESULTS OF THE TESTS.

It is proposed to give in some detail the results of the tests on the copper-manganese-aluminium and copper-manganese-tin alloys, and then to indicate the similarities

* J. G. Gray and A. D. Ross, *Proceedings of the Royal Philosophical Society of Glasgow*, 1910, p. 41.

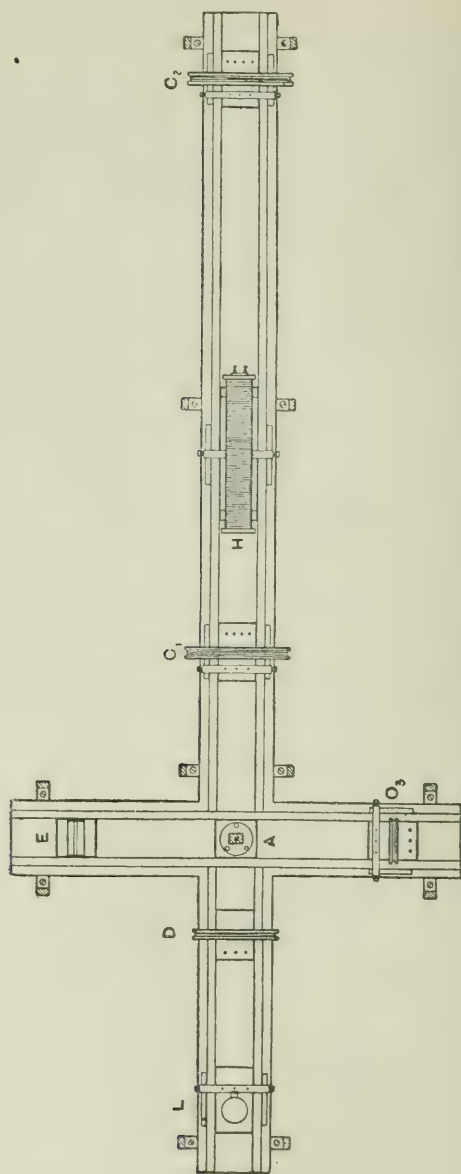


FIG. 1.—Plan of the Gray-Ross Magnetometer.

and differences found when the investigations were continued to the copper-manganese-antimony and copper-manganese-bismuth alloys. Afterwards a short résumé will be given of the work on the binary alloys and of the chief deductions drawn from the results.

COPPER-MANGANESE-ALUMINIUM AND COPPER-MANGANESE-TIN.

The alloys, to which reference will hereafter be made, were found on analysis to have the following compositions:—

TABLE I.—*Compositions of Cu + Mn + Al, and Cu + Mn + Sn Alloys.*

Alloy.	Percentage Composition.			
	Cu.	Mn.	Al.	Sn.
	Per Cent.	Per Cent.	Per Cent.	Per Cent.
1	75.5	16	8	...
2	62	25	12.5	...
3	54	30	15	...
4	60.2	25.1	...	14.1
5	58.7	23.5	...	16.1
6	57.6	24.9	...	18.0
7	49.2	20.4	...	29.8
8	43.4	18.1	...	40.0
9	36.4	15.0	...	48.1

Of the first group No. 2 was by far the most strongly magnetic, and in the second group No. 8 was the best. Nos. 7 and 9 were only very feebly magnetic. In what follows the results obtained for alloys 2 and 8 will generally be given, values being added for the others only when they show special features of interest.

The alloys were first of all tested as cast, that is, without any preliminary dressing operations, with the exception of the removal of the end portions as described above. Tests were made with the material (1) at room temperature, and (2) when cooled down to -190°C . For the latter test the specimen (A, Fig. 2) was placed in a glass tube (BCD), one end (B) of which was closed while the other (CD) was open and curved upwards. The tube was supported by cork bungs (FF), so that the specimen lay along the axis of the magnetising

solenoid (EE). Liquid air was poured in at D, and a steady temperature was soon attained, as the corks prevented access of warm air from without.

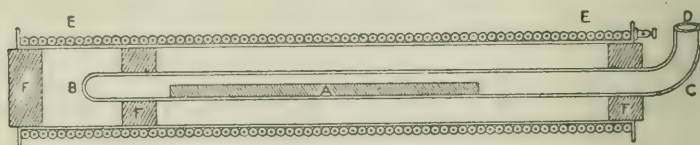


FIG. 2.—Apparatus for Low Temperature Tests.

Table II. gives the results obtained in tests at 15° and -190° C.

TABLE II.—*Tests at 15° and -190° C.*

Applied Field, H.	Intensity of Magnetisation.			
	Cu + Mn + Al. Alloy 2.		Cu + Mn + Sn. Alloy 8.	
	15°	-190°	15°	-190°
20	254	300	21	21
50	292	358	53	53
100	310	388	95	95
200	324	401	159	160
Residual	85	160	11	11

The effect of cooling to liquid-air temperature is large in the case of the aluminium alloy, and practically nil in the case of the tin alloy. This liquid-air effect, however, varies greatly in different members of the same series. Table III. gives the percentage improvement in the values of I corresponding to $H=100$ for the various alloys referred to in Table I.

TABLE III.—*Improvement in Quality by Cooling to -190° C.*

Alloy.	1	2	3	4	5	6	7	8	9
Percentage increase in I for $H=100$)	20	25	-1	21	26	35	1	0	0

The improvement in quality of these alloys on cooling to -190° is an interesting and somewhat characteristic feature, as most magnetic materials, such as iron, steel, iron alloys, nickel and cobalt, are in general less susceptible to magnetisation at low than at normal temperatures.

It has been found that the majority of those bronzes are improved in quality by exposure for some time to temperatures between 150° and 200° C. The improvement has usually a double origin. First, it removes the strains generally left in the material by the process of casting; and, secondly, it results in constitutional change, the material being brought into a new equilibrium condition. In most cases this improvement can be effected in two steps, corresponding with the two distinct processes involved. Thus, if the metal is heated to, say, 180° C., and then cooled comparatively slowly, the internal strains are removed. The alloy now gives a magnetisation curve of precisely similar shape to the initial one, but with each ordinate slightly larger. The percentage improvement in quality on cooling to -190° C. is unaltered—the thermal treatment has resulted merely in a “normalising” of the alloy. If now the metal be heated to the same temperature and kept thereat for several hours previous to the slow cooling back to room temperature, we have an annealing process resulting in constitutional change of the material, which is altered from a metastable condition towards the true equilibrium condition corresponding to temperatures not far removed from room temperature.

In the case of the copper-manganese-aluminium alloys the normalising has comparatively little effect, but considerable improvement can be obtained in some instances by annealing or baking at temperatures about 170° C. for six to eight hours. With alloy No. 2 this results in an increase in the saturation value of I of as much as 10 per cent., while the hysteresis is not appreciably augmented. It is different with the copper-manganese-tin alloys. Normalising not infrequently produces a decided improvement in quality, but annealing or baking results in an increased hysteresis loss which more than counterbalances any advantage derived from the slight improvement in susceptibility. Prolonged baking, especially at moderately

high temperatures, has invariably an adverse influence, although the resultant effect varies irregularly with the temperature employed,* pointing to complex structural changes.

The quenching of the alloys at high temperatures has revealed several interesting facts. The copper-manganese-aluminium alloys are always less magnetic after this treatment, but it is noteworthy that the coercive force, and consequently the hysteresis, are greatly diminished. Coercive force is a quantity which varies greatly in different materials, as will be seen from the figures given in Table IV.

TABLE IV.--*Coercive Forces.*

Material.	Coercive Force.
	C.G.S. Units.
Very soft iron	1.7
Cast iron	4
Annealed carbon steel	20
Quenched tungsten steel	50
Cu + Mn + Al alloy No. 2	1.3
Do. quenched at 550°	Less than 0.3
Cu + Mn + Sn alloy No. 8	9
Do. quenched at 400°	6

The exceedingly small value of the coercive force for alloy No. 2 after quenching at 550° is remarkable, considering that the material is still comparatively magnetic, having a permeability of over 100 for $H=20$, that is to say, a value little inferior to that for cobalt. The quenched alloys are in an unstable rather than a metastable condition. If left at room temperature for several months they gradually improve in magnetic quality, and finally attain a permeability little less than that which they had prior to the quenching. Thus a specimen of alloy No. 2, which had initially a permeability $\mu=160$ for $H=20$, had $\mu=130$ after quenching at 400° C. In the course of a year μ had risen to over 157. This improvement in quality was not accompanied by any appreciable increase in the small value of the coercive force for the quenched material. We thus obtain a material of fair per-

* A. D. Ross and R. C. Gray, *Proceedings of the Royal Society of Edinburgh*, 1909, vol. xxix. p. 274.

meability and with extremely little hysteresis loss. This is at least an approximation towards the ideal magnetic substance, which should be highly magnetic and without hysteresis. The recovery of magnetic susceptibility with time of the quenched copper-manganese-aluminium alloys was first pointed out by the author early in 1907.* Asteroth has since shown that the recovery can be accelerated by exposure of the alloy to a temperature of 140° or 160° C.† Heusler and Richarz have recently suggested that this material might be useful in the construction of electrical measuring instruments on account of its vanishingly small hysteresis.‡ In the author's opinion, however, this seems unlikely for several reasons. The alloys are exceedingly hard and brittle and almost unworkable. They are also very sensitive to change of temperature, and ageing from exposure to heat has a much more deleterious effect on them than on iron and steel.

As already stated, copper-manganese-aluminium alloys are always less magnetic after quenching, but the resultant susceptibility does not steadily diminish with increasing temperature of quenching. On the contrary, alloy No. 2 is much more magnetic after being quenched at 700° C. than after quenching at 600° C.

With the copper-manganese-tin alloys the effect of quenching is even more complex. When the quenching is carried out at temperatures high above the critical temperature the material is always rendered almost non-magnetic. But if quenching is carried out at moderate temperatures, the alloys are sometimes almost as magnetic as before this treatment.

An interesting point in regard to the quenched alloys of both groups is that they are nearly all more sensitive to temperature variations than they were in the unquenched condition. This is well shown by Table V., which compares the changes in I for $H=100$ produced in the unquenched and quenched materials respectively by cooling from 15° to -190° C.

* A. D. Ross, *Proceedings of the Royal Society of Edinburgh*, 1907, vol. xxvii, p. 88.

† P. Asteroth, *Inaugural-Dissertation*, Marburg, 1907; *Verhandlungen der Deutschen Physikalischen Gesellschaft*, 1908, vol. x, p. 21.

‡ F. Heusler and F. Richarz, *Zeitschrift für anorganische Chemie*, 1909, vol. lxi, p. 265.

TABLE V.—*Percentage Change in I for H = 100 on Cooling from 15° to -190° C.*

Alloy.	1	2	3	4	5	6	7	8	9
As cast . . .	+20	+25	-1	+21	+26	+35	+1	0	0
Quenched . . .	+400	+33	+50	+25	+33	+35	+5	+9	+5

The magnetic properties of the alloys have also been examined when the cast or normalised specimen is placed in an electric furnace and heated to various temperatures. The procedure usually consisted in carrying out a series of tests at successively increasing temperatures until the critical point was attained, and then the tests were repeated at the same temperatures taken in the reverse order as the specimen was allowed to cool down to room temperature again. The copper-manganese-aluminium and the copper-manganese-tin alloys behave very differently under this treatment. The former are much less magnetic at each definite temperature during the cooling process than they were at the same points during the heating. The tin alloys give similar magnetisation curves in the two stages. The manganese-tin bronzes are therefore reversible, whereas the manganese-aluminium bronzes are irreversible. The critical temperatures of the former alloys were found to range from 220° to 280° C., while those of the three copper-manganese-aluminium alloys were 280°, 500°, and 345°.

COPPER-MANGANESE-ANTIMONY AND COPPER-MANGANESE-BISMUTH.

Experiments made on copper-manganese-antimony alloys showed them to have properties very similar to those of the copper-manganese-aluminium alloys. The bismuth bronzes, however, differed in one or two important particulars from the others. The fact that these metals are ferromagnetic at all is rather remarkable when we consider the nature of the constituent elements. Manganese is only very feebly paramagnetic, while copper is slightly and bismuth com-

paratively strongly diamagnetic (that is to say, much less magnetic than what we commonly term empty space). Those elements nevertheless combine to give alloys with decidedly ferromagnetic properties. This will be seen from Table VI., which gives the results obtained in a test on an alloy with the approximate composition: copper 43 per cent., manganese 17 per cent., bismuth 39 per cent. This material became much more magnetic on quenching at 300°C ., the treatment resulting in an enhancement of over 60 per cent. in the intensity of magnetisation for an applied field of strength about 200 gauss. The retentivity was greatly increased, and the coercive force was also augmented instead of undergoing reduction as in the other ternary systems. Cooling to liquid air temperature lowered I for $H=200$ by over 30 per cent. in the case of the cast material, and by about half of this amount in the case of the alloy as quenched at 300°C .

TABLE VI.—*Magnetisation Curve for Alloy (Copper 43 per cent., Manganese 17 per cent., Bismuth 39 per cent.).*

Applied Field.	Intensity of Magnetisation.
50	2
100	5.5
200	12
Residual	2
Coercive force	Circa 40

BINARY ALLOYS.

Tests have been made on the binary alloys, copper-manganese, copper-aluminium, manganese-antimony, and manganese-boron, with two objects in view: (i.) to ascertain their susceptibility to magnetisation; and (ii.) in the case of the $\text{Cu} + \text{Mn}$ and $\text{Cu} + \text{Al}$ groups to compare their behaviour upon quenching, cooling to -190°C ., &c., with that of the ternary alloys.

A word or two will suffice as to the $\text{Mn} + \text{Sb}$ and $\text{Mn} + \text{B}$ groups. The former is the more magnetic, alloys approximating

in composition to the formula Mn_3Sb_2 being, comparatively speaking, fairly susceptible. Alloys corresponding roughly with the formula Mn_2Sb were less magnetic, somewhat more retentive, and had much greater coercive force. A manganese-boron alloy containing equal atomic proportions of the two elements was about as magnetic as Mn_2Sb , and exhibited much the same hysteresis. Owing to the impossibility of obtaining castings free from blow-holes, no attempt was made to measure the absolute values of the permeability of those materials.

The copper-manganese and copper-aluminium alloys were so feebly magnetic that it was not practicable to test them magnetically in the usual way. Short bars of the metal were placed in the narrow pole gap of a powerful electro-magnet in a field of nearly 5000 gauss. The residual magnetism of the specimen was thereafter tested by a delicate magnetometer. In comparing the results so obtained with those found in other cases by the ordinary I-H magnetometer test, it is very important to note that we must compare only residual intensities of magnetisation. High retentivity does not imply—as is too often assumed—high susceptibility. It is equally characteristic of bodies which are only moderately magnetic, but exhibit large coercive force.

Copper-manganese, containing about 30 per cent. of manganese, was found to be more retentive after quenching than in the cast condition. It thus differed essentially in magnetic properties from the manganese-aluminium and manganese-tin bronzes. On the other hand, an alloy containing about 10 per cent. aluminium and 90 per cent. copper gave effects very similar to those in the copper-manganese-aluminium alloys, viz. an improvement on cooling to liquid air temperature and a deterioration on quenching. A few other copper-aluminium alloys with widely varying compositions were tested, but the others did not show the same similarity to the ternary alloys.

THE MAGNETISM OF THE COPPER-MANGANESE-ALUMINIUM ALLOYS.

The 10 per cent. aluminium bronze referred to above differed from all the others tested in that it contained the

intermetallic compound Cu_3Al .* As alloys approximating in composition to this formula were apparently the most magnetic of the aluminium-copper series, the view was expressed that this compound played an important part in the magnetism of the copper-manganese-aluminium alloys.† Shortly afterwards Heusler and Richarz published a somewhat similar hypothesis based on tests of a different kind.‡ These experimenters, having gathered data for some thirty or forty manganese-aluminium bronzes, found that on marking the alloys on a ternary diagram (Fig. 3) the most highly magnetic lay approximately along the line joining the points which represent Cu_3Al and Mn_3Al . They accordingly advocated the theory that the ternary alloys contain magnetic compounds consisting of aluminium in chemical combination with manganese and copper so that in every case each atom of aluminium is associated with three atoms of the other metals. In other words, they postulate the occurrence of a series of ternary magnetic compounds represented by the general formula $\text{Cu}_x\text{Mn}_y\text{Al}_z$, where x and y may have any of the values 0, 1, 2, . . . , and $x + y = 3z$.

This theory seems unsatisfactory for several reasons:—

(1) Ternary compounds are almost unknown. Indeed, with the exception of CdHgNa and Hg_2KNa § we have no reliable evidence of their occurrence.

(2) No ternary compounds were found in the portion of the copper-manganese-aluminium system investigated by Rosenhain and Lantsberry, *although several of their alloys were decidedly magnetic.*||

(3) If such compounds did exist, there would be no reason why they should show quenching and liquid air effects identical to those in Cu_3Al . The extremely close correspondence between the magnetic behaviour of Cu_3Al and the

* For the compositions of aluminium-copper alloys, see H. C. H. Carpenter and C. A. Edwards, *Proceedings of the Institution of Mechanical Engineers*, 1907, p. 57; B. E. Curry, *Journal of Physical Chemistry*, 1907, vol. xi. p. 425.

† A. D. Ross and R. C. Gray, *Proceedings of the Royal Society of Edinburgh*, 1909, vol. xxix. p. 274.

‡ F. Heusler and F. Richarz, *Zeitschrift für anorganische Chemie*, 1909, vol. lxi. p. 265.

§ E. Jänecke, *Zeitschrift für physikalische Chemie*, 1906, vol. lvii. p. 507.

|| W. Rosenhain and F. Lantsberry, *Proceedings of the Institution of Mechanical Engineers*, 1910.

ternary bronzes would therefore be a chance coincidence, which seems very improbable.

On the other hand, the author adheres to his former view that the magnetic properties are due to the formation of solid solutions, of which the compound Cu_3Al is a constituent. Mn_3Al is known to be the most magnetic of the manganese-aluminium alloys.* It is possible, then, that a series of solid

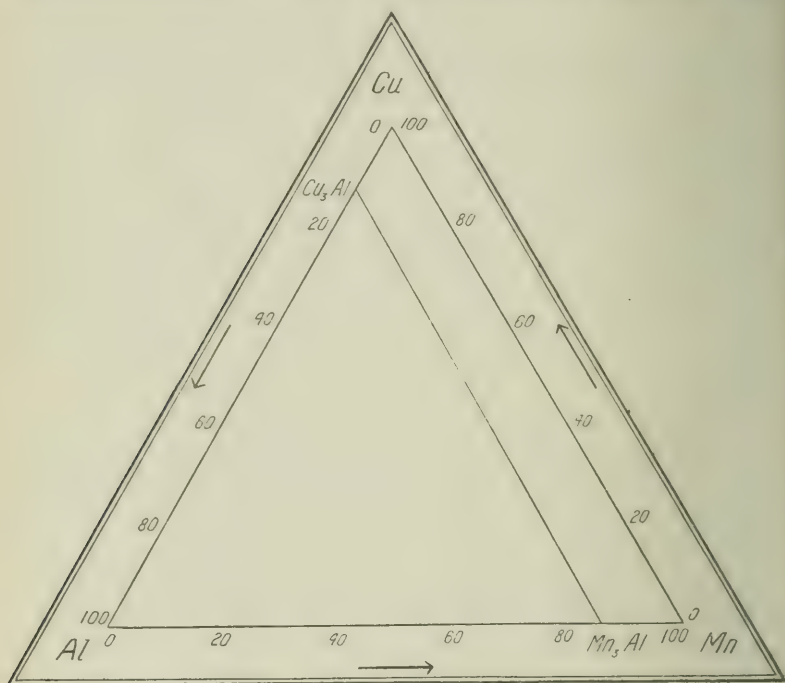


FIG. 3.—Copper-Manganese-Aluminium Ternary Diagram.

solutions occur between the compounds Cu_3Al and Mn_3Al , and give rise to the ferro-magnetism of the ternary alloys. It should be noted, however, that, owing to the great difficulty of obtaining satisfactory castings, no ternary alloys with less than 60 per cent. copper have been tested along the line joining Cu_3Al and Mn_3Al . Accordingly one cannot be certain as to whether the solid solutions are formed merely between

* G. Hindricks, *Zeitschrift für anorganische Chemie*, 1908, vol. lix. p. 414.

Cu_3Al and Mn_3Al , or whether uncombined manganese enters into them. There are certain considerations which make the presence of free manganese probable, and with a view to gaining further information on this point the author has taken in hand the microscopic examination of the ternary ferro-magnetic alloy and also magnetic tests on manganese-aluminium alloys.

It may be asked why solid solutions of Mn or Mn_3Al in Cu_3Al should result in the production of a material so much more magnetic than either of its constituents. No direct explanation can at present be given, but we have analogous instances. Thus the addition of small quantities of aluminium and other elements to iron with the formation of solid solutions leads to materials more magnetic than iron, although the added element is itself non-magnetic.* Again, copper-aluminium alloys containing aluminium in increasing proportions up to 8 per cent. consist of solid solutions which are the more retentive of magnetism the greater the amount of aluminium present.† Why the presence of a non-magnetic constituent should enhance the magnetic quality of a material is a difficult question to answer. Perhaps the action is somewhat similar to that in which we find nickel and other allied elements altering the recalescence point Ar_2 , at which iron transforms from the non-magnetic to the magnetic condition. The solution of the problem would be of great interest alike to physicists and metallurgists, and it seems probable that satisfactory progress is most likely to be attained by extensive magnetic tests on alloys conducted in combination with metallographic investigation.

The researches are not yet sufficiently advanced to permit of a discussion as to the origin of the magnetism of the copper-manganese-tin alloys. Meanwhile, however, it may be stated that a similar solid solution hypothesis seems applicable in this case also. It may be of interest to point out in this connection that the copper-manganese-tin alloys have been found to fall into two distinct magnetic groups,‡ and that

* W. F. Barrett and W. Brown, *Journal of the Institution of Electrical Engineers*, 1901, vol. xxxi. p. 675.

† R. C. Gray, *Proceedings of the Royal Philosophical Society of Glasgow*, 1910, p. 41.

‡ See p. 75.

manganese and tin form two magnetic compounds Mn_4Sn and Mn_2Sn ,* whereas manganese and aluminium form only one magnetic compound Mn_3Al .†

The work described in the present paper has been carried out in the Physical Institute of the University of Glasgow, and the author desires to acknowledge his indebtedness to Professor Gray for the facilities granted for conducting the investigations.

* R. S. Williams, *Zeitschrift für anorganische Chemie*, 1907, vol. lv. p. 1.

† G. Hindricks, *ibid.*, 1908, vol. lix. p. 414.

DISCUSSION.

Professor H. C. H. CARPENTER, M.A., Vice-President, said the first point he would like to refer to was that all those alloys showing ferro-magnetism which had been investigated by Mr. Ross contained manganese. Of course that manganese always contained a small amount of iron. Mr. Ross had dealt with that point, and considered, apparently, that the influence of iron was negligible. He would like to ask whether Mr. Ross had found ferro-magnetism in any of the alloys made from non-magnetic material which did not contain manganese. Until that had been done it would be unwise to conclude that the influence of the iron in the manganese was quite negligible. He was very glad to see that Mr. Ross had taken up the investigation of the structure of those alloys, and he thought it might be expected to throw some light on the origin of their ferro-magnetism. The research, however, was difficult. He (Professor Carpenter) had had some experience with these alloys, and their great hardness and brittleness created difficulties in the technique of polishing and etching. He had a small criticism to offer with regard to page 85. Mr. Ross there mentioned the influence of the addition of small quantities of aluminium in increasing the ferro-magnetism of iron itself. He (Professor Carpenter) had done some work for Professor Barrett with those very alloys, and he had arrived at a different conclusion with regard to the influence of aluminium from that reached by Mr. Ross. Reference had been made to the possibility of aluminium forming a solid solution with the iron which increased the magnetism. Personally, he did not think this was the cause. It was well known that the purest forms of commercial iron always contained some iron oxide. From the microscopic investigation he concluded that the action of aluminium consisted in reducing the iron oxide distributed through the metal, thus forming alumina and purifying the iron. This should increase its magnetic permeability. He concluded by expressing his interest in the paper and his appreciation of its value.

Professor A. GRAY (Glasgow) remarked that he found a little difficulty in saying anything about Mr. Ross's paper, as he was interested in various researches now in progress and bearing on points mentioned in the paper. The communication was one of a large series which Mr. Ross had worked out in the laboratory at the University, and the facts set out were typical of many others which had been discovered in the course of those researches. For example, in the investigation of manganese steels, there had been found one which was commonly supposed to be entirely non-magnetic, but which could be made very highly magnetic indeed by proper treatment. The view that seemed to prevail, that an alloy of that kind was a perfectly definite thing which retained its properties under all circumstances, was entirely wrong. The President had referred to the fact that people thought copper was copper, and therefore always the same, whereas it was often quite a different thing.

Similarly, the behaviour of metals as regards magnetism and other properties, depended upon the treatment they received. Thus a particular heat treatment resulted in a remarkable increase in the magnetism of manganese steels.

Some similar effects mentioned in the paper might perhaps to some extent be explained by the fact that there was iron present in the manganese. It was a very remarkable thing that a small amount of iron present in the manganese would give effects immensely greater than might be expected from iron existing alone. For example, they had taken some specimens of copper supplied to them as being chemically pure, but which were found on analysis to contain a very small amount of iron. The magnetism of this material was many times greater than that which they would have expected from the amount of iron present, even if supposed to be of the very highest permeability. It was clear, therefore, that the iron present had an effect upon the arrangement and structure of the molecules which formed the alloy. To his mind, the important thing was the arrangement of the molecules (he was using the word in a particular sense) of the alloy. They could magnetise some things but not others. This was due to the breaking up, where that was possible, of molecular groupings. It was a question of turning the molecules round and causing them to rearrange themselves. The treatment to which the substance had been subjected, and the presence of other bodies, such as a little aluminium, or manganese, or iron, had an effect upon the substance, causing it to undergo rearrangements as the result of applied magnetic force—magnetic force acting upon already existing magnetic molecules.

It might be possible to investigate some changes by means of the microscope, but those magnetic changes to which he had referred were beyond the power of the microscope. Some recent researches which had been carried out, and were referred to in the paper, showed very different magnetic effects produced under different circumstances, and these might be associated with different microstructures.

He would like to direct their attention to one point on page 78, viz. the diminution in hysteresis. In these substances with certain treatment the hysteresis was considerable. After quenching of the material the susceptibility diminished, the hysteresis diminished, and the coercive force diminished. Gradually, with the lapse of time, the original magnetic susceptibility was recovered, while the small hysteresis and the coercive force remained unaltered. He thought that was a very remarkable fact.

MR. J. H. HEAP (London) said there was one question he would like to ask Mr. Ross relative to a statement on page 68, which read as follows: "Thus chrome and tungsten steels, on account of their great retentivity, are specially suited for the preparation of permanent magnets." He had seen that statement made a good many times, and he would like to ask whether as a matter of fact tungsten did enter into the composition of magnet steel.

It seemed to him that the paper opened up a very important subject,

and he was sorry to hear Professor Gray say that the conditions which he described as affecting that question were such as could hardly be investigated by the microscope. He was inclined to think that the metallographic study of those alloys ought to throw a great deal of light on their magnetic properties, and this belief was supported by various other investigations that had been made. It was in fact likely to give more information than the study of their chemical composition.

MR. E. L. RHEAD, M.Sc. Tech. (Manchester), said that he wished to add a few words to what had been already said in connection with magnetic alloys. Some four years ago, two students working in his laboratory, namely, Messrs. Evans and M'Craith, took up a somewhat extended study of the effects following the addition of various metals to manganese with a view of ascertaining the magnetic effect produced upon it. Those alloys were all binary alloys. They were working with the idea that possibly the effect of the added metal was to so alter the character of the manganese itself as to confer magnetic value upon it. They found that certain groups of metals were particularly active in producing that change. Zinc and cadmium in that group were tried, and magnetic values of considerable amount were obtained. The most remarkable effects were those obtained with the group in which antimony and bismuth were found, not only in regard to the metallic members, but with regard to others. They came to the conclusion that phosphorus and arsenic added to manganese had the same effect, although not in the same degree. They thought, in view of the results obtained, they had some ground for believing that if metals with similar chemical properties, whose compounds crystallised very much in the same form, were employed, the effect of those additions was to so alter the crystalline structure of the material as to account for the magnetic value obtained. They worked for some time, with a view to obtaining confirmation by metallographic methods. Up to the present he must admit their success was only partial.

The fact that manganese entered into those alloys they regarded as a minor circumstance, their view being that it was a metal that was more readily affected than others, and was thus more readily sensitised. Their instruments were not so delicate as those mentioned by a former speaker, in which he was able to obtain magnetic effects with other metals. Perhaps that was the reason why, in his own experiments, he was not able to get satisfactory results from them. He was, however, entirely in accord with the speaker that probably the magnetic value, or the magnetic character, was dependent upon the arrangement of the molecules. In the case of manganese, it was possible that a fixed arrangement was obtained by the addition of other metals in such a way as to retain the magnetic effects. He thought it would be found in reading the admirable paper presented by Mr. Ross, that the effect of the heat treatment to which the alloys had been subjected in the course of the experiments would rather tend to confirm the idea that it was the rearrangement of the molecules which produced an alteration in the

crystalline form and that was responsible for the magnetic effects obtained with manganese. On page 72, for example, and also on page 77, there were references to heat treatment. There was a reference to annealing or baking at a temperature of 170° , that might similarly be construed as showing the effects of alterations in crystalline structure. In other cases, if the paper were carefully read, the same deduction might very fairly be drawn.

It was possible that the addition of copper to the binary alloys referred to was of value largely in acting as a solvent to the constituents of the alloy, and would thus separate the particles, and render them freer, as well as lowering the melting point, so that in the solidification of the alloys the necessary arrangement of the molecules could to a certain extent be taken on naturally, permanently affecting the character of the alloy.

Mr. J. S. GLEN PRIMROSE (Glasgow) considered that the paper was of very great interest from several points of view. The one specially interesting to himself was the fact that the structure of the alloys might furnish some reason for the magnetism found to be present. Those members who had the privilege of reading the recent report of the Alloys Research Committee would remember that Dr. Rosenhain mentioned some matters bearing on this question. The alloys which he had found to be distinctly magnetic all lay within a certain range on the diagram showing the structure of alloys. The microstructure had been examined by him, and in that field it would be noticed quite distinctly on comparison with the other micrographs given, that there was a difference from the alloys showing less magnetic effect, that was to say, it was similar to certain steels which had been overheated. There was an intrusion of the dark constituent into the light-coloured portion of the field. Possibly those were the two constituents of the alloy, which Mr. Ross pointed out had become magnetic, and were more so when combined than when apart, hence he thought that the suggestion to have the microstructure afterwards examined should reveal something of great interest. The whole point of the cause of magnetic effect was one merely of conjecture in the meantime, but he thought it would be interesting to have further information on that subject. It would be of very great service if they could have those alloys (particularly the one Mr. Ross specially mentioned as having a very low hysteresis) made of commercial value in the alloy-making trade, enabling them to produce material requiring certain properties requisite for delicate electrical instruments.

Mr. C. H. WILSON, Member of Council, inquired with regard to a paragraph on the top of page 72, in which it was said: "When moist sand was tried, it was found that the material was invariably of somewhat inferior magnetic quality and could not be brought quite up to the standard by annealing or other heat treatment." He would like to know whether Mr. Ross could give any explanation of that, and what the effect would be on the structure of the alloy.

Mr. Ross, in reply, said he was glad the paper had evoked considerable discussion, several of the points raised being of great importance. The small hysteresis of the quenched material was extremely important both from a theoretical and practical point of view. Professor Carpenter and Professor Gray had referred to iron in the manganese as possibly concerned in the magnetic properties. The fact that alloys containing much larger amounts of iron had almost identical properties showed, however, that the iron had no considerable effect. With regard to the magnetisation of copper itself, they had examined specimens of almost pure copper, the iron impurity being an extremely small trace. That material in its ordinary condition was diamagnetic, but after quenching was ferromagnetic and possessed feeble retentivity. He thought the effect must be ascribed to some impurity. They had tested the material at the temperature of liquid air, and the result on cooling was completely different to what would be expected if one accepted the influence of the iron. If then the effects were due to iron, it certainly did not act like pure iron. As to the addition of aluminium to iron giving an improved material, it was very probable, as Dr. Carpenter pointed out, that the aluminium acted largely as a deoxidiser. At the same time he thought that tests on aluminium-iron alloys had shown a more magnetic substance than even pure iron. Mr. Heap had referred to tungsten steel. He had analysed a magnet steel and found the presence of chromium and tungsten, and from researches conducted in the laboratory he knew that a 4 per cent. tungsten steel was very retentive. In reply to Mr. Wilson he would say that casting in moist sand was to some extent equivalent to quenching. The resulting alloy was less magnetic, and he had found no heat treatment which would afterwards raise the material to standard permeability.

He had pleasure in exhibiting three specimens of the alloys which had been ground on emery. One had been ground to ellipsoidal form in Professor Barr's laboratory, and the work was exceedingly difficult * and occupied several days.

* The addition of a small amount of lead to a copper-manganese-aluminium alloy renders it somewhat less difficult to work, and does not diminish, but rather enhances, the magnetic permeability.

THE HEAT-TREATMENT OF BRASS

EXPERIMENTS ON 70:30 ALLOY.

BY G. D. BENGOUGH, M.A., AND O. F. HUDSON, M.Sc.

Objects.—The objects of the present investigation were:—

1. To study the effects of heat-treatment on rolled and drawn 70:30 brass of varying size of section and of somewhat varying character, as made by different manufacturers.

2. To throw some light on the question of “burning.” For the purposes of the present paper a sample of brass is considered to be burnt, when its ductility, as measured by the percentage elongation, has been lowered by heat-treatment.

Historical.—The most important researches on similar subjects have been carried out by Charpy, Grard, and Cubillo. Charpy’s * work, which consisted of an investigation into the constitution, structure, and properties of alloys of copper and zinc, included a number of experiments on the effect of annealing on 70:30 brass. His results are given in Table I., and may be compared with those obtained by the authors. His conclusions on the question of burning were as follows:— (1) 70:30 brass made from pure copper and pure zinc was not burnt after annealing at 900°C . (2) Ordinary 70:30 brass (0.15 per cent. tin and 0.2 per cent. lead) is burnt by heating to 800°C . His results, however, were not very definite, and he only examined the question from the point of view of temperature. The authors, on the other hand, have endeavoured to ascertain by what means the temperature has effected the deterioration in properties—whether by volatilisation of zinc, by excessive crystalline growth, or by mere loss of cohesion between the molecules at high temperatures, in which case permanent deterioration may result from careless handling. The influence of time has also been taken into account.

Grard’s † experiments were mainly directed to ascertaining

* *Bulletin de la Société d’Encouragement l’Étude des Alliages*, p. 1.

† *Revue de Métallurgie, Mémoires*, 1909, p. 1069.

in a quantitative manner the effect of work on α -brass, and the exact temperature at which that effect was removed. With a constant annealing time of fifty minutes (using test-bars of 52 sq. mm. and 60 sq. mm. in cross section) the elastic limit was found to fall off very slightly up to 200° C., then more rapidly to 300° C., and beyond that temperature more slowly to 825° C., when it was very small. The breaking load was practically unaffected below 275° C., but between 275° C. and 300° C. it fell off rapidly, and then more slowly to 900° C. No effect was produced on the ductility as measured by elongation by annealing temperatures up to 250° C. From 275° C. to 300° C. there was a rapid increase in the elongation, and from that temperature a regular increase up to 825° C., after which the elongation decreased as the annealing temperature became higher. Grard also investigated the effect of varying time of annealing for the lower temperatures, and found that at 300° C. one hour was required to produce any noticeable change in the strength or ductility, while at 400° C. annealing for ten minutes was sufficient to produce a marked effect. For temperatures above about 500° C. to about 650° C. annealing for more than one hour had little further effect on the strength or ductility. Grard also examined the microstructures of the annealed bars, but his work throws little new light on the question of burning.

Cubillo* sets forth his experience as a manufacturer of brass for cartridge and other purposes, but gives no details of experimental results. His paper deals with effect rather than cause.

Material used in the Present Research.—A $\frac{3}{4}$ -inch round bar of ordinary high-grade 70:30 brass was supplied in the hard-rolled condition by a well-known firm. This bar was cut into test-pieces, lettered G, and may be taken as representing the ordinary 70:30 brass of commerce. Its analysis was as follows:—

	Per Cent.
Copper	71.0
Tin	0.02
Lead	0.25
Iron	0.2

* *Engineering*, October 27, 1905.

To compare with this, another bar of $\frac{3}{4}$ -inch round hard-rolled 70:30 brass was supplied by another firm. This bar was cut into test-pieces, lettered HB. Its analysis was as follows:—

	Per Cent.
Copper	69.4
Tin	trace
Lead	0.005
Iron	0.15

It will be noticed that this alloy is of unusual purity. The same firm also supplied to the authors a third bar, B, of similar material, having the following analysis:—

	Per Cent.
Copper	69.7
Tin	trace
Lead	trace
Iron	0.2

This bar was 1-inch round, and was in a softer state than the others. It was mainly used for some experiments on the effect of prolonged annealing at high and other temperatures.

All this material was such as is supplied by the manufacturers in the ordinary way of business to their customers.

Scheme of Work.—The bars as received from the makers were cut into 9-inch lengths, turned into test-bars according to the

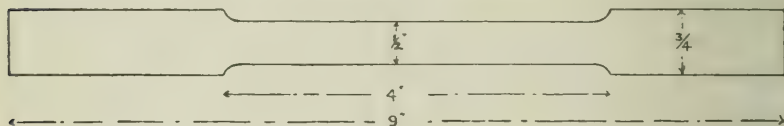


FIG. 1.

accompanying sketch (Fig. 1), and heated in electrically-heated tube furnaces, the temperatures of which were ascertained and controlled by thermo-electric pyrometers. After annealing, the bars were withdrawn at a dull red heat, cooled in air, and tested in the ordinary way. Before testing, a piece was cut from each test-bar for microscopic examination. With a view to ascertaining the influence of size of section, a hard-drawn $\frac{1}{8}$ -inch diameter wire of brass similar to bar G was annealed at the same time as the test-bars. Test-pieces of this wire

were also heated in an electric resistance furnace to temperatures between 300°C. and 600°C. , and tested while at these temperatures. Various subsidiary sets of experiments were also made, particularly on the question of "burnt brass."

EFFECT OF ANNEALING TEMPERATURE.

The results of the ordinary tensile tests on bars and wires annealed for half-an-hour are given in Tables II. to IV., and plotted graphically in Figs. 2 to 6. From these results the following facts are evident:—

1. *Maximum Stress.*—In all cases the maximum stress increases with rise in annealing temperature up to about 300°C. It then falls off rapidly to 500°C. The HB bar evidently had received more work than the G bar or the wire, and, in consequence, there is a much greater numerical loss of strength between these temperatures. Nevertheless, for temperatures between 500°C. and 800°C. , the strength of the HB test-bars is in all cases superior to that of the G bars, though the superiority gradually diminishes as the temperature rises, and has disappeared at 850°C. As regards the wire, the strength falls off uniformly from 500°C. to 900°C. , and is, for all temperatures, less than that even of the G bars, the difference increasing as the temperature rises. It will be seen later that prolonging the time of annealing has the effect of lowering the strength of a bar; it would also seem from the above that decreasing the section has a similar effect. The corollary at first sight would seem to be to proportion the time of annealing to the section of the bar, and so to avoid burning thick sections by annealing at higher temperatures. It will be seen later, however, that time is at least as important a factor in burning as temperature. It does not seem, therefore, that any decided advantage can be claimed for the method suggested over the rival one of proportioning the temperature to the section. As a matter of fact, both plans are used in works, some managers favouring one, and some the other.

2. *Yield Point.*—The yield points given in these tables are the stresses required to give the first noticeable elongation, but, except in the case of the bars as hard-rolled, and in a few

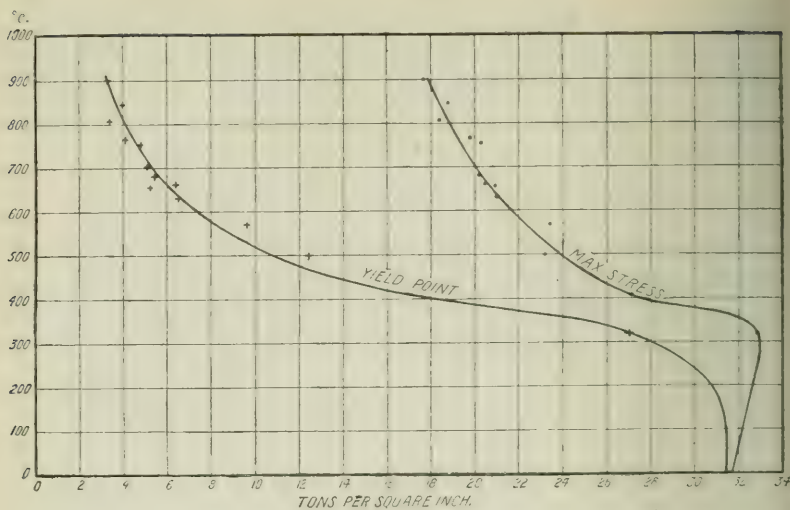


FIG. 2.—Bars HP.

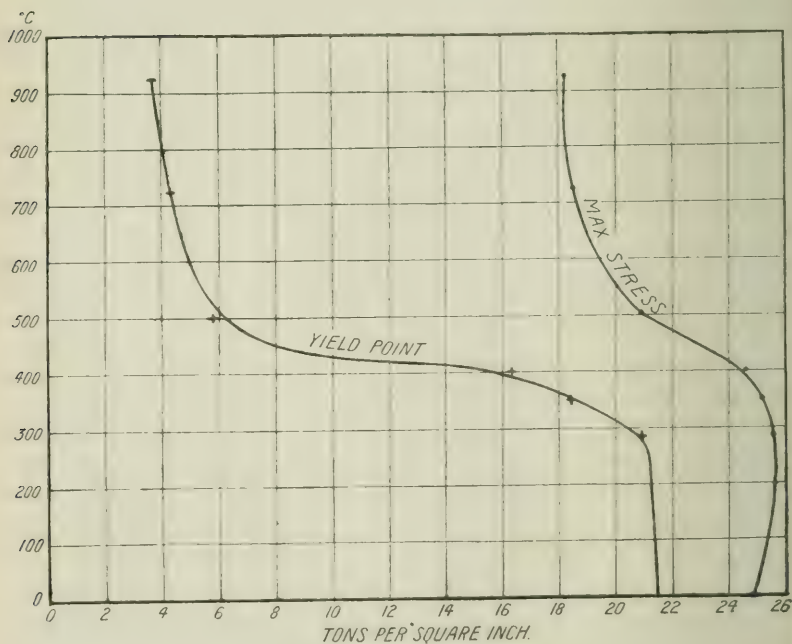


FIG. 3.—Bars G.

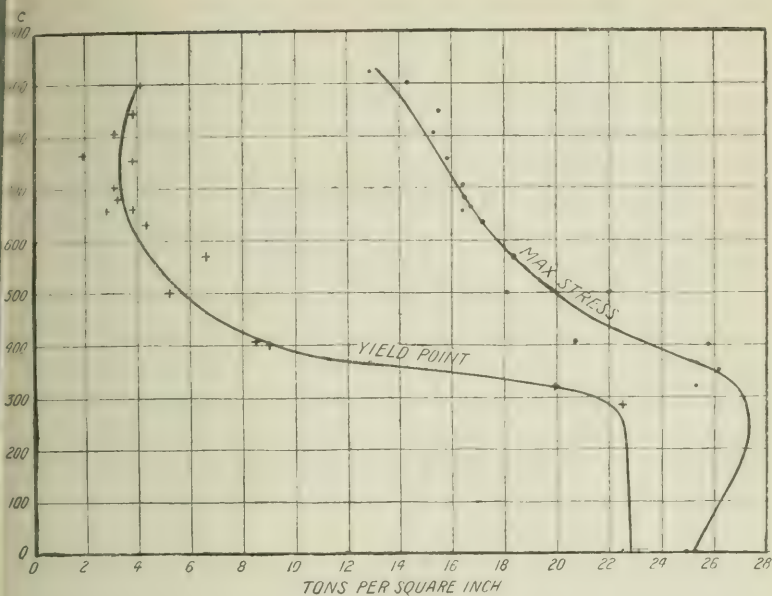


FIG. 4.--Wires.

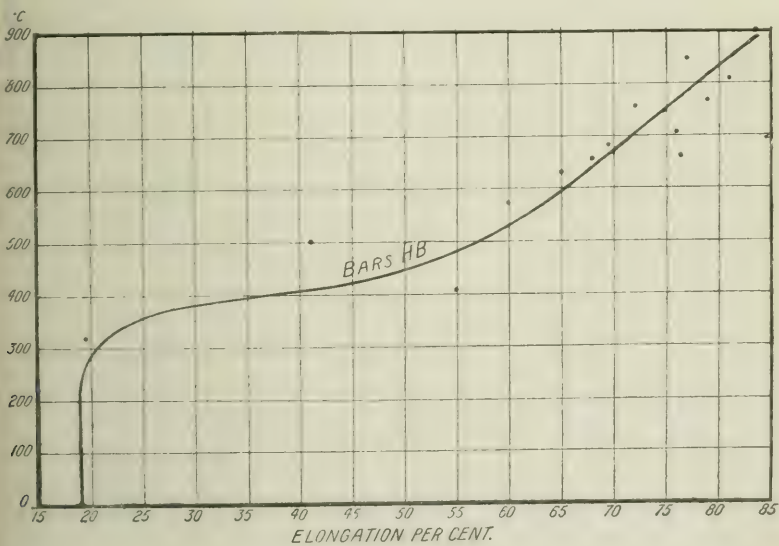


FIG. 5.

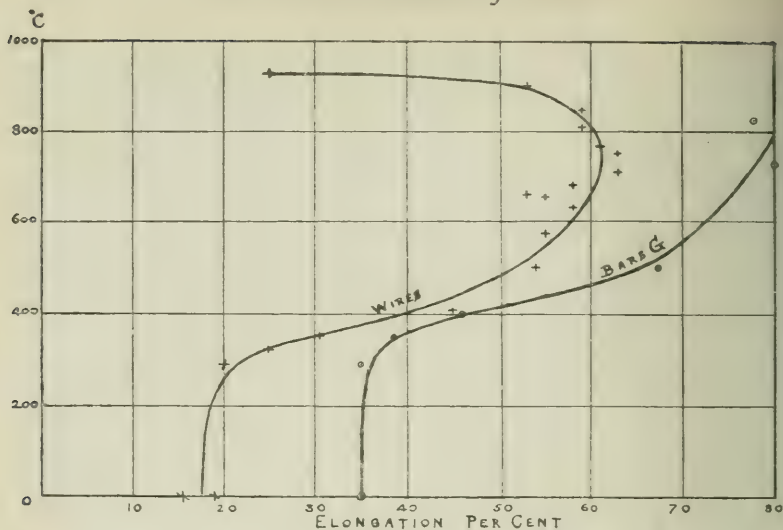


FIG. 6.

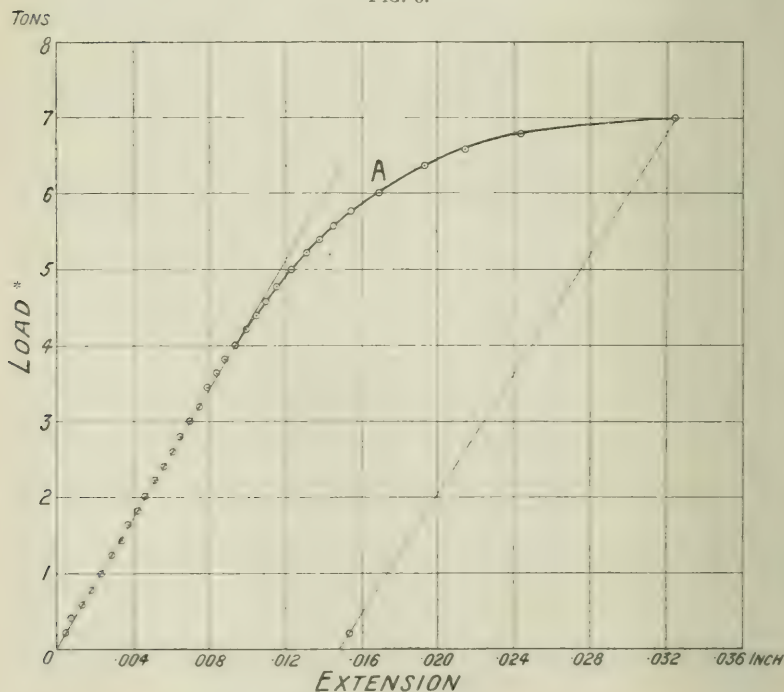


FIG. 7.

* The loads given are actual loads on a sectional area of 0.479 square inch.

other cases, the yield point is not very sharply defined. The curves given in Figs. 2-4 show in a general way the effect of annealing temperatures on the yield point. It will be noticed that these curves have been drawn practically vertical between 0° and 100° C. This has been done because it has been shown in connection with tests for the determination of elastic limit that annealing for one hour at about 100° C. has no effect on the yield point.

3. *Elastic Limit*.—It was thought that it would be interesting to make a determination of the true elastic limit in the case of one of the alloys used, and to ascertain whether any definite load existed which could be strictly regarded as a sharply defined yield point: also, if it existed, what relation this had to the elastic limit. This determination was made on the B alloy, using a bar with screwed ends, 16 inches long and 12 inches between shoulders. A stress-strain curve is shown in Fig. 7. The elastic limit is at 8.35 tons per square inch. The yield point cannot be strictly defined, but the extension which occurs at 12.5 tons would probably be the first which would be easily recognised in ordinary testing. This point is marked by the letter A in the stress-strain diagram. It was thought that it would be interesting to make a few experiments as to the effects of a period of rest, and of very low annealing temperatures on the elastic limit. The results obtained are shown in Table V. It will be seen (1) that a prolonged period of rest raises the yield point: (2) that annealing for 1 hour at 90° C. has no effect whatever; and (3) that annealing for 1 hour at 210° C. has very considerably lowered both elastic limit and yield point.

4. *Elongation*.—In all cases the elongation is not much affected until an annealing temperature of 300° C. is passed. Just above this temperature a very rapid increase occurs in the case of the wires. In the case of the bars the rapid increase sets in at about 350° – 400° C. Here again an increase in size of section seems to require a longer time of annealing to produce similar results. The maximum elongation is reached with an annealing temperature of 750° C. for the wires, and with approximately the same temperature

for the bars G. In both these cases a diminution seems to occur with annealing temperatures above 800°C . For the HB bars, on the other hand, the elongation appears to increase regularly up to a temperature of 900°C .

5. *Contraction of Area*.—In a general way the variations in this property follow those in elongation. It may be remarked, however, that burning appears to manifest itself first by a falling off in the contraction of area.

INFLUENCE OF TIME IN ANNEALING.

The above remarks apply only to bars annealed for half-an-hour. The tests given in Table IX. were made for the purpose of comparison with the tests referred to.

In the case of the bars B, *i.e.* of the brass free from tin and lead, annealing for one week at 440° or seven hours at 665°C . has practically no effect. Annealing for twenty-four hours at 750°C . causes a lowering of the maximum stress, but the elongation of 81 per cent. on 2 inches indicates that the alloy is not injured by this treatment. Similarly it will be noticed that annealing for twenty-four hours at 810°C ., although causing a still further lowering of the maximum stress, has not produced any effect that indicates "burning." Bar B9, which was annealed for only six hours at 840° – 850°C ., shows a marked lowering of the elongation and contraction of area, and has suffered by this treatment a distinct deterioration. Lastly, an annealing for seven hours at 900° – 910°C . has resulted in a further very noticeable weakening of the material, accompanied by a pronounced loss of ductility. A comparison of the mechanical properties of bars B17 and B9 with those of bars HB9 and HB13, of similar material, annealed for only half-an-hour at 900°C ., points very clearly to the important effect of time in annealing at very high temperatures. It need hardly, however, be said that such very drastic treatment as bar B17 has received is very unlikely to occur in practice. These experiments, therefore, cannot be claimed to have ascertained the cause of the phenomenon of burning, which is said to occur occasionally even in the best-regulated works.

COMPARATIVE EFFECTS OF OXIDISING AND REDUCING GASES
IN THE ANNEALING FURNACE.

It was thought possible that the presence of reducing gases in the annealing furnace might, at unduly high temperatures, cause a reduction of small amounts of oxide or slag contained in the metal, and thus affect its mechanical properties, especially in the case of the G bars, which contain a certain amount of impurities. Accordingly bars G0, G1, G2, G3, G4 were annealed in an atmosphere of coal gas. The results are given in Table VI. It will be seen that annealing for three hours at 825°C . has in no way injured the alloy, but that seven hours at 850°C . has produced a distinct deterioration, as shown by the elongation. Three hours at 900°C . has also injured the alloy, and $2\frac{1}{2}$ hours at 920° – 930° has altogether ruined it. Comparing these with the similar tests (Table VII.) carried out in an oxidising atmosphere, it seems probable that the presence of reducing gases is at any rate not a predominant factor in the production of burnt brass, since annealing in an oxidising atmosphere produces very similar effects.

The authors wish to express their acknowledgments to Mr. F. H. Hummel, M.Sc., for his assistance and interest in many of the tensile tests detailed above.

LOSS OF ZINC BY VOLATILISATION.

It has been suggested* that loss of zinc by volatilisation may be one cause of the phenomenon of burning. The following experiments were therefore made to test this:—Turnings were taken at various depths from the exterior of certain of the bars after they had been annealed at the higher temperatures, and estimations of the percentage of copper made on each sample taken. The results are recorded in Table VIII. It will be seen that the exterior layers, to a depth of $\frac{1}{8}$ inch, showed an increase in the copper (*i.e.* a loss of zinc) of 1.5 per cent. after being annealed for half-an-hour at 850° – 900°C . The loss of zinc decreases as the distance from the surface increases, and at a depth of about $\frac{1}{16}$ inch the loss of zinc by

* C. H. Desch, *Metallography*, p. 387.

volatilisation is almost negligible. For a bar, such as HB6, which was annealed for half-an-hour at 700°C ., the loss is small, and amounts to only 0.5 per cent. on the exterior layer of $\frac{1}{64}$ inch. For a longer annealing time, and for bars that were known to be distinctly burnt, the loss of zinc was considerably higher, amounting in one case (G2) to 5.5 per cent. It will be seen that this loss is approximately five times that lost by HB9, which was annealed at about the same temperature for half-an-hour. But even in this case the loss of zinc by volatilisation almost ceases to be appreciable at a very short distance from the surface of the bar, and consequently the ratio of zinc lost to total zinc originally present must be small. Moreover, the zinc does not appear to be removed by violent evolution, but by gentle diffusion and evaporation from the surface. It seems to the authors probable that the removal of zinc is not a primary cause of burning, but merely an accompaniment of that phenomenon. To a very limited extent it occurs also at ordinary annealing temperatures.

TESTS AT HIGH TEMPERATURES.

It was thought that it would be interesting to carry out a series of tests on one of the alloys *at* various temperatures, so as to afford a comparison with those of the similar alloys which have been merely annealed at a high temperature and afterwards tested cold.

The method used for carrying out these tests was as follows:—A length of wire was clamped at the top end and heated in a vertical electric resistance furnace. From the bottom end of the wire a stirrup was hung on which could be placed a series of standard weights. It was found that the speed of loading had a considerable effect on the maximum stress, especially at the higher temperatures. The figures for this property, which are given in the table of results (Table X.), correspond to the load required to break the wire in from 15 to 20 minutes. It was found that any attempt to mark the test-wires with punch marks, or fine scratches made with a steel or diamond point, localised the fracture, particularly at temperatures above 400° . To get over this

difficulty fine graphite marks were made on the wires at distances apart of 1 inch; these were used for determining the elongation in the ordinary way. This plan was found to be satisfactory up to a temperature of 500°C . At temperatures in the neighbourhood of 600°C . some difficulty was experienced in recognising these marks owing to the large

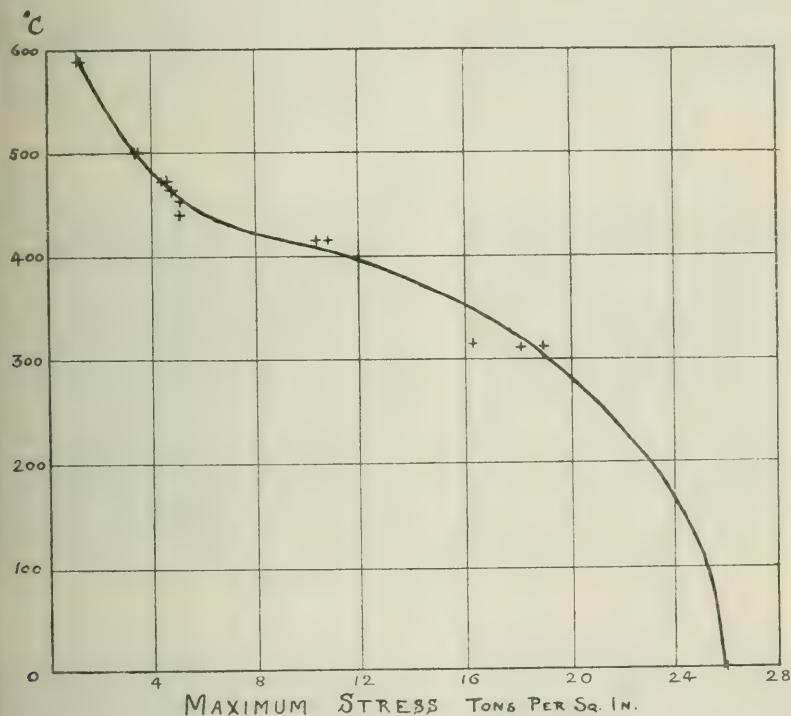


FIG. 8.—Tests at High Temperatures.

amount of oxidation of the alloy. The figures for the wires tested at 590°C . may, however, be said to be reliable, since four results agreeing fairly closely have been obtained. No temperatures higher than 600°C . have so far been used in these tests, owing to the difficulty mentioned. The results are given in Table X., and are plotted in Figs. 8 and 9. It will be noticed that the maximum stress falls off fairly regularly up to the highest temperature at which tests were

carried out. At 590°C . the strength has been reduced to but little more than 1 ton per square inch. The elongation falls off to the very low values of 2.5 per cent. on 2 inches at 310°C ., and 1.5 per cent. at 415°C . A recovery sets in after this, and a new maximum value is obtained at a temperature between 450°C . and 475°C . At still higher

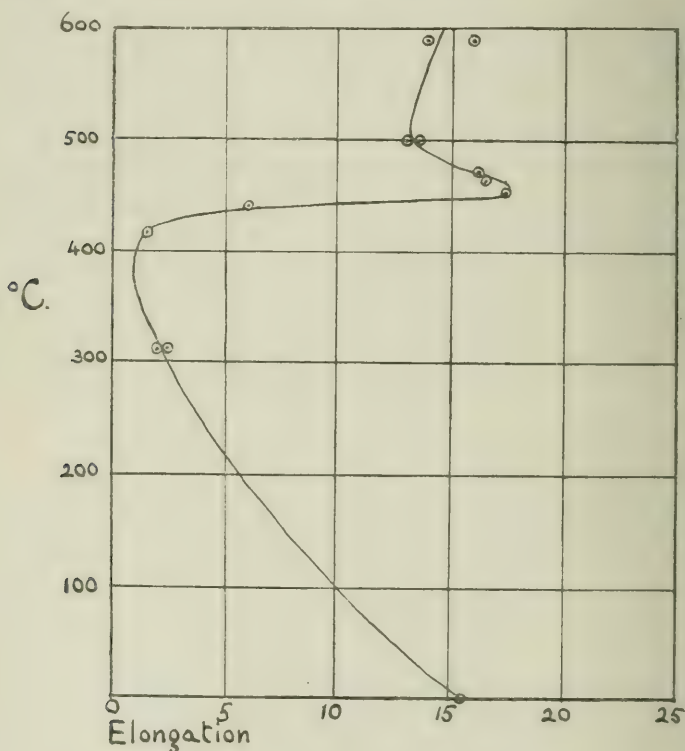


FIG. 10.—Tests at High Temperatures.

temperatures a second falling-off is observable, but it is not so pronounced as that at the lower temperatures. At 590°C . the wire still has an elongation of about 15 per cent. It will be observed that at the comparatively low temperature of 600°C . the alloy has lost 95 per cent. of its strength, and its ductility is only some 15 per cent. At higher temperatures it seems probable, from the shapes of the curves that

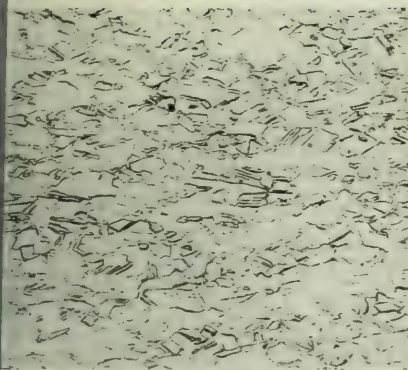


FIG. 1.—Bar HB as rolled.

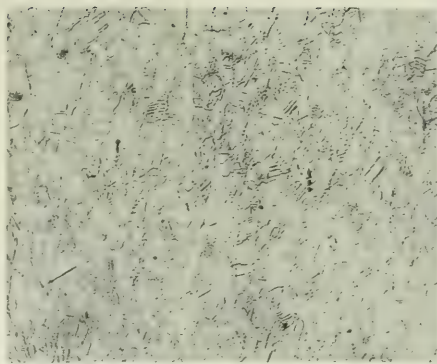


FIG. 2.—Bar HB14. Half-hour at 320° C.

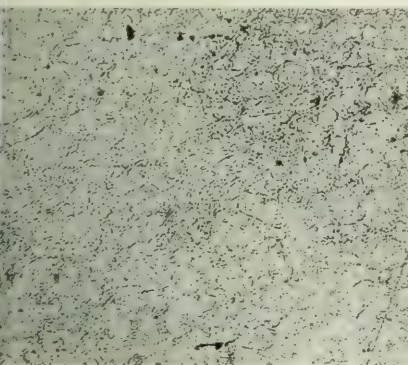


FIG. 3.—Bar HB10. Half-hour at 405° C.

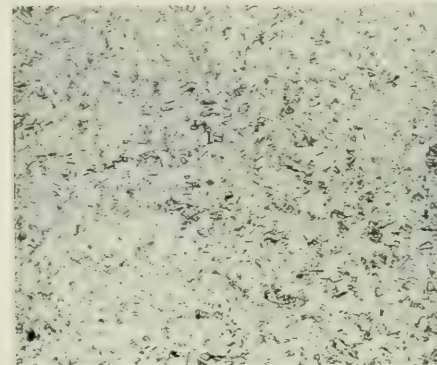


FIG. 4.—HB1. Half-hour at 500° C.

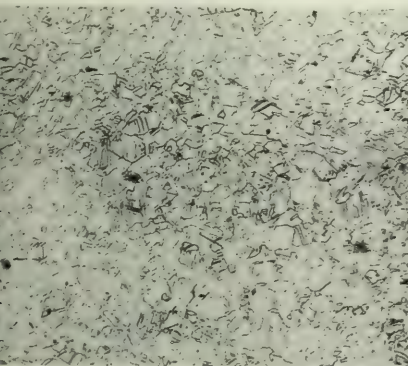


FIG. 5.—Bar HB2. Half-hour at 570° C.

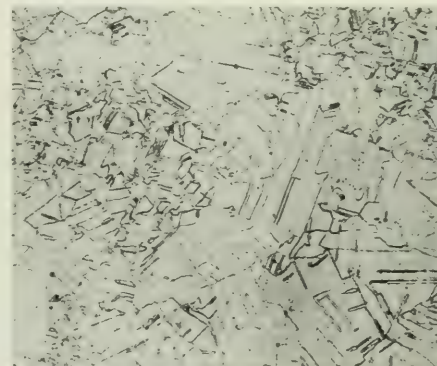


FIG. 6.—Bar HB3. Half-hour at 630° C.

Magnification—100 diameters (reduced 20 per cent. in reproduction), Illumination—Vertical.



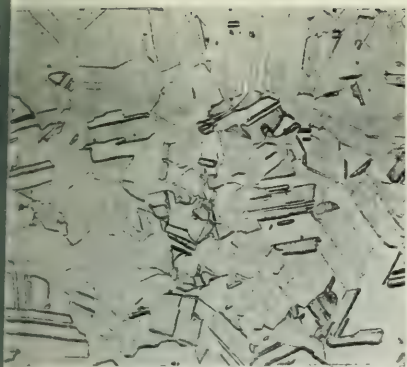


FIG. 7.—Bar HB12. Half-hour at 657° C.

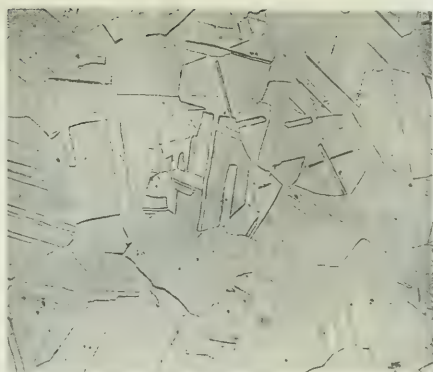


FIG. 8.—Bar HB11. Half-hour at 754° C.

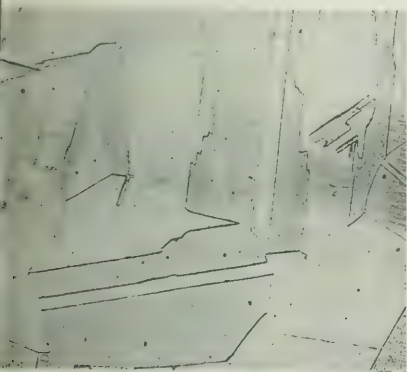


FIG. 9.—Bar HB8. Half-hour at 808° C.

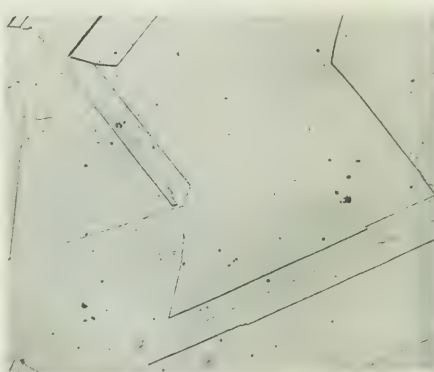


FIG. 10.—Bar HB9. Half-hour at 990° C.

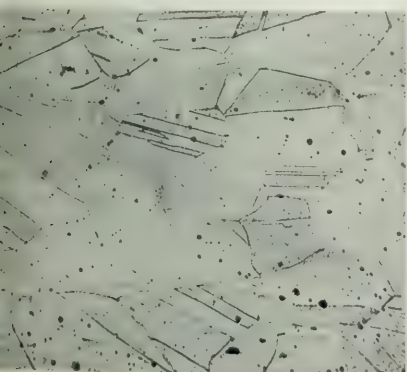


FIG. 11.—Bar G as rolled, r



FIG. 12.—Bar G15. Half-hour at 285° C.

Magnification—100 diameters (reduced 20 per cent. in reproduction). Illumination—Vertical.

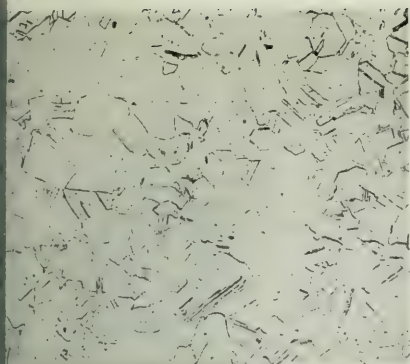


FIG. 13.—Bar G18. Half-hour at 500° C.

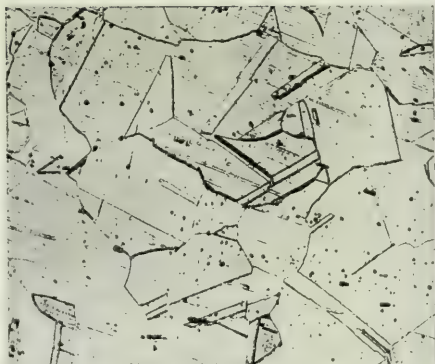


FIG. 14.—Bar G21. Half-hour at 725° C.

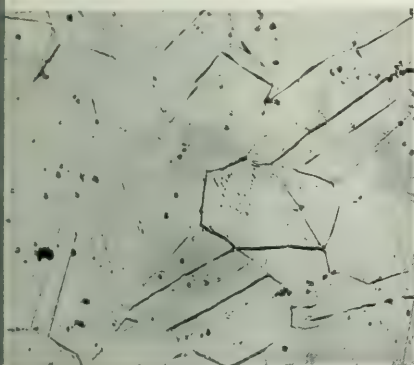


FIG. 15.—Bar G25. 2 hours at 920-925° C.



FIG. 16.—Bar G27. One hour at 910° C.

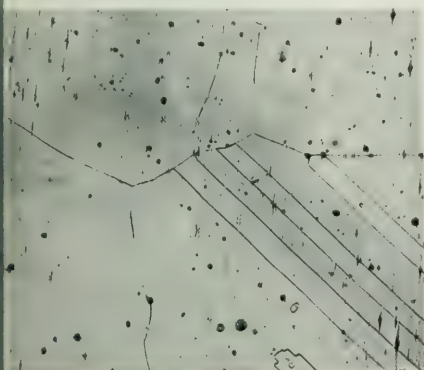


FIG. 17.—Bar G28. 3 hours at 910-920° C.



FIG. 18.—Bar G2. Two and a half hours at 920-930° C., in reducing atmosphere.

Magnification—100 diameters (reduced 20 per cent. in reproduction). Illumination—Vertical.



the maximum stress will suffer further diminution. Thus at the temperature of an ordinary annealing furnace, say 650°C ., the mechanical properties of the alloy in question are such as to require somewhat careful handling, a fact which is doubtless familiar to all who are engaged in the manufacture of brass alloys. If, however, the temperature of the annealing furnace were to rise somewhat higher than that usually employed, it seems possible that the maximum stress might fall off to such a low figure as to be a source of serious difficulty whenever it becomes necessary to handle the alloy. It seems possible, too, that any handling of the material at even a slightly higher temperature than usual, though it may not actually fracture it, may cause a permanent deterioration of its properties.

MICROSCOPIC WORK.

The microstructure of the bars after annealing and before testing was examined, and typical structures are illustrated by photographs reproduced in Plates I. to III. The general effect of annealing on the crystalline structure of 70:30 brass is now a matter of common knowledge, but there are one or two points that may perhaps be noted here with advantage.

1. *Annealed Structures*.—The first effect of annealing on a rolled or otherwise strained sample of brass is to bring any altered and crushed material into a condition suitable for subsequent recrystallisation. As the temperature rises, recrystallisation sets in from a large number of new centres, the result being that after annealing for half-an-hour at 500°C . the structure appears very distinctly finer than in the original bar as rolled (see Figs. 1, 4, 5, 11, and 13, Plates I., II., and III.). From this point crystal growth proceeds rapidly.

2. *Over-annealed Structures*.—The result of annealing at an unduly high temperature is a very rapid crystalline growth, which causes the coarse structure characteristic of over-annealed brass. After a certain time this very rapid growth of crystals probably slows down, and the size of crystals approaches a maximum value.* Possibly there is a definite

* Reference may be made here to the work of Ewing and Rosenham on crystal growth after annealing, *Metallographist*, 1902, p. 81.

size of crystal characteristic of each temperature, which is not affected by time once equilibrium has been reached.

3. *The Microstructure of Burnt Brass.*—As far as the authors have been able to ascertain, the structure of burnt brass, in the case of the material used for this work, closely resembles over-annealed brass, with a possible difference that the lead segregates in the crystal boundaries. They have found no sign of the pitted structure, which is generally said to be characteristic of burnt brass, except with very deep etching.

4. *The Effect of Lead.*—The presence of lead is indicated by small, more or less rounded, particles scattered through the crystals. When the brass containing lead has been annealed at a very high temperature, there is a tendency for the lead to segregate between the crystals, and this effect seems to increase with the time of annealing.

GENERAL SUMMARY.

1. The effects of various annealing temperatures upon the mechanical properties of cold-tested brass bars of commercial quality have been studied in detail. The best combination of strength and ductility appears to be obtained for annealing temperatures between 600°C . and 700°C . This is in accordance with the results obtained by previous workers.

2. The true elastic limit has been determined for one of the alloys used. This alloy did not appear to have a very well-defined yield point, such as is exhibited, for example, in the case of mild steel.

3. The effects of varying the annealing period have been investigated. This factor has an even more important effect on the mechanical properties than the temperature factor. A temperature but a few degrees below the solidus, if only maintained for half-an-hour, will not seriously burn a bar of pure brass. A temperature nearly 100°C . lower will burn the brass if it is maintained for a sufficiently long time. Even small quantities of impurity have an important effect in increasing the tendency to burn. This last effect has previously been recorded by Charpy.

4. It has been shown that the atmosphere of the annealing furnace, whether oxidising or reducing, does not appear to affect in any well-marked manner the properties of brass.

5. A few determinations of the loss of zinc by volatilisation during the annealing process have been made. This loss is appreciable, but is mainly a surface effect. The authors do not consider this to be the *cause* of burning.

6. Tests have been made on the mechanical properties of brass wire at high temperatures. It has been found that the maximum stress falls off continuously. The elongation and contraction of area, on the other hand, fall off to a very low value at temperatures between 300°C. and 400°C. , after which a recovery of ductility occurs, and is practically maintained even at 590°C. , the highest temperature employed. The suggestion is made that any handling of the material at a slightly higher temperature than usual may cause a permanent deterioration in its properties.

7. The microstructures of annealed, over-annealed, and burnt brass have been studied and illustrated, and new facts as to crystal growth in brass at low annealing temperatures have been recorded.

The authors have so far dealt with the heat-treatment of α -brasses and the $\alpha + \beta$ -brasses containing an excess of α . They propose to take up the study of alloys containing an excess of β , both as pure copper-zinc and as complex alloys.

TABLE I. (A).—70:30 Brass.*

Annealing Temperature.	Maximum Stress.
Degrees C.	Tons per Sq. In.
0	31.4
200	32.5
280	29.5
420	21.6
500	21.6
560	19.0
600	17.4
650	17.4
730	18.6
780	18.2
800	18.2
850	18.2

* Charpy's results.

TABLE I. (B).—70·30 Brass, with 0·15 per Cent. Tin and 0·2 per Cent. Lead.*

Annealing Temperature.	Maximum Stress.	Elongation.
Degrees C.	Tons per Sq. In.	Per Cent.
0	39·4	3·8
540	20·3	55·0
585	20·1	57·3
620	19·0	60·8
700	18·6	64·8
730	19·0	62·0
860	17·5	57·0
930	16·8	56·5

TABLE II.—*Mechanical Tests of Bars HB.*

Mark.	Treatment, Time, and Temperature of Annealing.	Yield Point, Tons per Sq. In.	Maximum Stress, Tons per Sq. In.	Elongation, per Cent. on 2 Ins.	Contraction of Area, per Cent.	Surface of Bar after Test.
HB	As rolled.	31·5	31·7	19·0	65·0	Smooth.
HB14	$\frac{1}{2}$ hour, 320° C.	27·4	32·9	19·5	65·5	..
HB10	$\frac{1}{2}$ hour, 405° C.	11·3	25·1	55·0	75·5	..
HB1	$\frac{1}{2}$ hour, 500° C.	12·4	23·2	†41·0	72·0	..
HB2	$\frac{1}{2}$ hour, 570° C.	9·6	23·4	60·0	77·0	..
HB3	$\frac{1}{2}$ hour, 630° C.	6·5	21·0	65·0	75·0	..
HB12	$\frac{1}{2}$ hour, 657° C.	5·3	20·95	68·0	81·0	..
HB4	$\frac{1}{2}$ hour, 660° C.	6·4	20·5	76·5	80·0	..
HB5	$\frac{1}{2}$ hour, 680° C.	5·4	20·2	70·0	77·0	{ Very slightly roughened.
HB6	$\frac{1}{2}$ hour, 702° C.	5·1	20·0	76·0	77·0	..
HB11	$\frac{1}{2}$ hour, 754° C.	4·8	20·3	72·0	80·0	{ Slightly roughened.
HB7	$\frac{1}{2}$ hour, 765° C.	4·1	19·8	79·0	70·0	..
HB8	$\frac{1}{2}$ hour, 808° C.	3·4	18·4	81·0	75·0	Roughened.
HB13	$\frac{1}{2}$ hour, 847° C.	4·0	18·8	77·0	73·0	..
HB9	$\frac{1}{2}$ hour, 900° C.	3·3	17·7	83·5	70·0	..

TABLE III.—*Mechanical Tests, Bars G, Half-hour Annealings.*

Mark.	Treatment, Time, and Temperature of Annealing.	Yield Point, Tons per Sq. In.	Maximum Stress, Tons per Sq. In.	Elongation, per Cent. on 2 In.	Contraction of Area per Cent.	Surface of Bar after Test.
G	As rolled.	21·5	25·0	35·0	65·0	Smooth.
G15	$\frac{1}{2}$ hour, 285° C.	20·9	25·6	35·0	66·0	..
G16	$\frac{1}{2}$ hour, 350° C.	18·4	25·2	38·5	53·0	{ Slightly roughened.
G17	$\frac{1}{2}$ hour, 400° C.	16·3	24·6	46·0	53·5	Smooth.
G18	$\frac{1}{2}$ hour, 500° C.	5·8	20·9	67·5	74·5	{ Slightly roughened.
G21	$\frac{1}{2}$ hour, 725° C.	4·3	18·5	80·0	75·0	Roughened.
G26	$\frac{1}{2}$ hour, 920°–925° C.	3·7	18·2	78·0	63·0	Cracked.

* Charpy's results.

† Broke outside gauge marks.

TABLE IV.—*Mechanical Tests of Wires.*

Mark.	Treatment, Time, and Temperature of Annealing.	Yield Point, Tons per Sq. In.	Maximum Stress, Tons per Sq. In.	Elongation, per Cent. on 2 In.
W0	As drawn.	23.1	25.3	15.5
W0	As drawn.	22.5	25.0	19.0
W15	$\frac{1}{2}$ hour, 285° C.	22.5	28.5	20.0
W14	1 hour, 320° C.	19.9	25.3	25.0
W16	1 hour, 350° C.	18.2	26.2	30.5
W10	1 hour, 405° C.	8.5	20.7	45.0
W8	1 hour, 500° C.	5.2	18.1	54.0
W9	1 hour, 570° C.	6.6	18.4	55.0
W4	1 hour, 630° C.	4.3	17.1	58.0
W12	1 hour, 657° C.	2.8	16.4	55.0
W1	1 hour, 660° C.	3.8	16.7	*53.0
W7	1 hour, 680° C.	3.2	16.5	58.0
W3	1 hour, 702° C.	3.1	16.4	63.0
W11	1 hour, 754° C.	3.8	15.8	63.0
W2	1 hour, 765° C.	1.9	14.7	61.0
W6	1 hour, 808° C.	3.1	15.3	59.0
W13	1 hour, 847° C.	3.8	15.5	59.0
W5	1 hour, 900° C.	4.1	14.3	53.0
W26	1 hour, 925° C.	?	12.9	25.0
W25	2 hours, 910° C.	...	10.5	18.0

* Broke outside gauge marks.

TABLE V.—*Determination of Elastic Limit, Bar B. Diameter of Test-Piece, 0.781 inch.*

No. of Loading.	Treatment.	Elastic Limit, Tons per Sq. In.	Yield Point, Tons per Sq. In.
1	As rolled.	8.35	12.5
2	...	8.35	14.0
3	12 days after No. 2	8.35	15.2
4	1 hour, at 90° C.	8.35	15.4
5	1 hour, at 210° C.	5.0	7.0

TABLE VI.—*Mechanical Tests, G Bars Annealed in Reducing Temperatures.*

Mark.	Treatment, Time, and Temperature of Annealing.	Yield Point, Tons per Sq. In.	Maximum Stress, Tons per Sq. In.	Elongation, per Cent. on 2 In.	Contraction of Area per Cent.	Surface of Bar after Test.
G0	3 hours, 700° C.	5.9	21.5	68	66	Smooth.
G1	3 hours, 825° C.	3.7	18.6	80	70	Slightly roughened.
G4	7 hours, 850° C.	...	17.1	62	...	
G3	3 hours, 900° C.	3.5	16.8	58	...	...
G2*	2½ hours, 920°–930° C.	3.7	15.3	41	32.7	Badly cracked.

* This bar showed signs of melting.

TABLE VII.—*Mechanical Tests, Bars G Annealed at High Temperatures in an Oxidising Atmosphere.*

Mark.	Treatment, Time, and Temperature of Annealing.	Yield Point, Tons per Sq. In.	Maximum Stress, Tons per Sq. In.	Elongation, per Cent. on 2 Ins.	Contraction of Area per Cent.	Surface of Bar after Test.
G25 .	2 hours, 920°–925° C.	4·5	18·0	67·0	70·6	Roughened.
G27 .	1 hour, 910° C.	3·6	17·25	71·0	51·3	Cracked.
G28 .	3 hours, 910°–920° C.	3·4	16·4	62·5	49·7	Badly cracked.
G29 .	3 hours, 910°–920° C.	3·0	16·9	64·5	47·0	Cracked.

TABLE VIII.—*Loss of Zinc by Volatilisation.*

Bar.	Treatment.	Distance from Surface.	Percentage of Copper.
G2 . . .	Annealed for 2½ hours at 920°–930° C. in a reducing atmosphere	0 – ¼ in.	76·7
		¼ – ⅜ in.	75·3
		⅜ – ½ in.	72·3
		½ – ⅞ in.	71·5
		⅞ – 1 in.	71·2
G27a . . .	Annealed for 1 hour at 930° C. in an oxidising atmosphere	0 – ¼ in.	75·7
		¼ – ⅜ in.	74·4
		⅜ – ½ in.	70·6
HB9. . . .	Annealed for ½ hour at 900° C.	0 – ¼ in.	70·8
		¼ – ⅜ in.	70·0
		⅜ – ½ in.	69·7
		½ – ¾ in.	69·4
HB6. . . .	Annealed for ½ hour at 700° C.	0 – ¼ in.	69·9
		¼ – ⅜ in.	69·7
		⅜ – ½ in.	69·8
		½ – ¾ in.	69·5

TABLE IX.—*Mechanical Tests—Bars B.*

Mark.	Treatment, Time, and Temperature of Annealing.	Maximum Stress, Tons per Sq. In.	Elongation, per Cent. on 2 Ins.	Contraction of Area per Cent.	Surface of Bar after Test.
B5 .	As rolled	22.4	65.0	78	Smooth.
B6 .	"	22.25	57.0	76	"
B3 .	1 week, 444° C.	22.2	62.5	70	.....
B4 .	1 week, 440° C.	22.6	70.3	72	.....
B1 .	7 hours, 665° C.*	21.85	70.5	77	Smooth.
B2 .	7 hours, 665° C.*	22.25	69.5	76	
B7 .	24 hours, 750° C.	19.6	81.0	...	{ Slightly roughened.
B8 .	24 hours, 750° C.	19.5	81.0	...	
B12 .	½ hour, 860° C.	17.7	87.5	...	Roughened.
B16 .	24 hours, 810° C.	17.3	85.5	75	"
B9 .	6 hours, 840°-850° C.	17.3	70.5	68	Cracked.
B17 .	7 hours, 900°-910° C.	15.6	†50.5	54	Badly cracked.

* Yield point 7 tons per square inch.

† Broke outside gauge marks.

TABLE X.—*Wires tested at High Temperatures.*

Mark.	Tested at Degrees C.	Maximum Stress, Tons per Sq. In.	Elongation, per Cent. on 2 Ins.	Contraction of Area per Cent.
W29	310	18.1	2.5	11
W31	310	19.0	2.0	10
W30	313	16.3	2.0	2
W32	415	10.8	1.5	10
W33	415	10.3	1.5	9
W38	440	5.1	6.0	15
W39	453	5.1	17.5	30
W34	465	4.8	16.5	29
W35	472	4.4	16.25	29
W36	472	4.6	16.25	29
W40	500	3.4	13.7	28
W41	500	3.5	13.0	22
W42	590	1.3	16.0	22
W43	590	1.2	14.0	18

DISCUSSION.

The PRESIDENT, in asking Mr. Bengough to read his paper, jointly prepared with Mr. O. F. Hudson, on "The Heat-treatment of Brass—Experiments on 70 : 30 Alloy," said most of the papers would raise discussions, and that was especially true of this. He understood this was written with the object of raising discussion, and especially to encourage the members to impart what information they had. He hoped they would hear a great deal in the course of the next few days which would enlighten them as to the various metals before them.

The President added that he did not propose to make many comments, but he hoped that the subject would be well discussed, and that gentlemen would not hesitate to say what they had to say. They could do with help from every direction. He thought that the Institute had done its work very effectually. When they began their discussions on the first paper things were something like the condition described at the Creation. They were without form and void. None of them had had any opportunity of gathering information on the subject of non-ferrous metals. Everybody had his own opinion, and everybody knew a little bit. Some of them thought they were the only people who knew anything. They were now convinced they did not know quite so much as they had thought they did. There was an extraordinary diversity of opinion amongst all classes of members. Nearly all of them, representing manufacturing members, scientific members, and practical members, had their own views on certain phenomena they had observed; but he thought that at the present time they were gradually boiling things down until now they had got a little bit of solid ground here and there, and there did appear to be some sort of agreement. As they joined in discussing the few points before them, they might find a nucleus which would serve as a bridge on which to build. They had had reports of papers read, and looking back it seemed to him that a matter of vital importance to the practical man, and a big question of pressing importance, was that of oxygen and oxides in copper alloys. They all seemed to be arriving at the conclusion that the crux of the whole question with which they were dealing, as they had had before them the various papers and discussions, was the question of heat-treatment. In the papers coming before them they would find that question raised again and again, and he did not think too much importance could be attached to that question of the temperature employed in casting. That was a matter of vital importance in regard to all material; and also after the casting had taken place, the question of the rate of cooling was a matter of great importance. Experience showed very marked results. Every manufacturer was aware that those two elements had a very marked effect, and the subsequent treatment of a casting was specially important. They knew that an alteration of temperature in annealing would entirely alter the results and would make all the difference in the character of the metal. A difference of 200° would make metal good

or bad. On those points they were to a large extent agreed. As far as he could gather from the various papers introduced, and from some discussions he had had with members, they had arrived at some points of agreement in certain directions, and they might hope to build a little. But they wanted a great deal more experiment and research before they had done with those questions.

He wished to impress upon all investigators that it was better not to confine their attention to one or two individual experiments. It was undesirable that upon a few experiments they should make arbitrary statements such as "such a thing is so and so because I have done it." It was possible to make experiments which in the first instance gave a certain result, and which gave the result they were looking for, and which they expected, but when they made further experiments—a slight variation either in the composition of the material, the introduction of an oxide, or a small matter of heat-treatment—they might get an entirely different result. It was desirable in making experiments to test in different directions. For example, if they tried oxidation or deoxidation upon the best selected copper or electrolytic copper as compared with tough coppers, they would get a totally different result, and a totally different line of effect. Some of the members in discussing the question of copper, referred to copper as if it was always copper and nothing else. But the variations of copper were almost as great, taking copper alone, as the variations of copper alloys. Therefore, all those experiments should be carried out from half-a-dozen different points of view.

They had now among them a comparatively new science, namely, metallography, and they all knew that that science had not been sufficiently used in works practice. Sufficient advantage had not been taken of the use of the microscope, although it was capable of furnishing an immense amount of information. They had a paper to come before them which furnished them with a great deal of information on that subject. He hoped they would have many more to follow it. The microscope might be very serviceable to the man who knew how to use it.

Mr. BENGOUGH, in introducing the paper, said that in the authors' view a bar was burnt when it was in a condition of unusual susceptibility to cracking. That condition might be attained as an effect of annealing at very high temperatures and for very long times. Thereafter under mechanical stress it would crack. A similar condition might be attained by a simultaneous application of stress and comparatively low temperatures such as 320° C. to 420° C. That definition of burning was to be taken as an extension of that given on page 92.

The analyses of the materials used in the research given on pages 93 and 94 did not include the figures for zinc. These were as follows:—

Bar G	Zn = 27.65 per cent.
Bar H E	Zn = 28.30 ..
Bar B	Zn = 29.50 ..

On the top of page 100 the statement occurred: "In both these cases a diminution seems to occur at high annealing temperatures above 800° C."

The authors thought that too much reliance should not be placed on the exact results of tests carried out on brass bars or wires annealed at very high temperatures. They appeared to vary somewhat, and any slight inhomogeneousness in the bar produced exaggerated effects at high temperatures. The authors believed, however, that the general form of the curve was as shown. In proof of this they desired to mention the following additional tests of wires which were drawn from G-bars, and which clearly confirmed the turning back of the curve at high temperatures:—

Annealing Temperature.	Annealing Time.	Maximum Stress.	Elongation.
900	$\frac{1}{2}$ hour	15·8	60
910	$\frac{1}{2}$ hour	13·8	55
920	$\frac{1}{2}$ hour	15·2	45

On page 104 the results of tests carried out on wires at high temperatures were given. In a Report to the British Association, published in 1899, Unwin obtained the following results on rolled yellow brass at high temperatures, the alloy being heated in an oil bath:—

Temperature of Test, Degrees C.	Maximum Stress.	Elongation, per Cent. on 2 Inches.
15	24·09	41·0
125	22·40	30·5
205	21·20	19·0
250	18·30	5·0
315	15·80	2·5
335	14·50	1·0

Unwin did not carry out his tests at temperatures above 350° C., and so did not observe the interesting recovery in durability to which they wished to draw particular attention.

Referring to the micrographs, all sections were longitudinal, and showed the effect of cold rolling up to an annealing temperature of nearly 400° C. Fig. 2 should be turned through a right angle. All micrographs were taken with vertical illumination, which the authors thought preferable to the usual oblique method, providing a suitable method of preparation was adopted. That took rather more time and care when the operator was unaccustomed to it, but was well worth doing. The authors would like to call particular attention to the difference in structure shown in Figs. 3 and 4, and also to the fact that Fig. 4 showed a distinctly finer structure than Fig. 1 (cold rolled), although it was of a bar that had been annealed at 500° C. That showed that recrystallisation

had set in. The authors would welcome the views of other members on that point.

On page 106, five lines from the bottom, the word "burn" should be replaced by "seriously burn."

In conclusion, Mr. Bengough said that he and Mr. Hudson were by no means under the impression that they had solved all the problems in connection with the annealing, over-annealing, and burning of brass; they had merely completed their original scheme of work on that alloy, but hoped to carry out further experiments as soon as time permitted.

Professor CARPENTER said the paper was a good example of the careful and accurate work they had learned to associate with the names of Messrs. Bengough and Hudson. With regard to the question of burning, he was glad that Mr. Bengough had indicated that he might still do some more work on brass of that type, because he did not think that question was yet settled, and he did not think the authors themselves wished to convey that impression in their paper. He should like to put forward a suggestion that might possibly have some bearing on that question. As Mr. Bengough had shown quite clearly, it was a very complex effect, in which temperature, time, and possibly the kind of atmosphere were conditions which might enter. He would like to ask them whether, in the microscopical examination of any of their burnt specimens, they had noticed the separation of a second constituent. Their experiments had been made with the 70 : 30 brass, which contained only the α constituent. He had been looking through Shepherd's paper on brass, and it was stated that in a great many specimens of burnt brass which had been experimented with, he (Shepherd) thought he observed a separation of the β constituent. None of the authors' photographs showed this, and he would like to ask them whether they had noticed anything bearing out that suggestion. If that was the case, it threw a light on the question of burning. The β constituent would be brittle, and would have an embrittling effect on the brass. He would like to know if they had observed anything in the nature of a second constituent in their burnt brass. Turning to page 106, in their summary No. 3, he noticed the authors said something which seemed to have a bearing on that: "Even small quantities of impurities have an important effect in increasing the tendency to burn." That was just what one would expect, if it was a question of the inversion of α into $\alpha + \beta$ at high temperatures.

A point very interesting to himself in the paper was the curve on page 104. There the authors showed the effect upon ductility of brass wire tested at various temperatures. That diagram was a very striking one. It showed that starting from the ordinary temperature, the ductility almost disappeared at about 400°, whereas at 460° to 470° it had risen to about 17 per cent. With the scientific knowledge they had at present, that rise was quite inexplicable. The Shepherd diagram, which was the latest work on the subject, gave no indication why that happened. He was going to put forward the view that there was an inversion in the 70 : 30 brass at about 450° C. which had hitherto escaped the notice of

all except perhaps one investigator. Sir William Roberts-Austen, in his Fourth Alloys Research Report, included a horizontal line at about 450° in the equilibrium diagram of the copper-zinc alloys. Shepherd, in his work on that diagram, which took three years to produce, said that line was an error. Now he (Professor Carpenter) was convinced that it was not. For some time Mr. Edwards and he at Manchester had been led to think that there must be an inversion in certain brass alloys somewhere in the neighbourhood of 500° C. They had been able to detect it pyrometrically, and they had thus confirmed Roberts-Austen's data, and had shown that after all he was really right. He did not wish to say more than that at present, but he hoped that their paper dealing with that point might be read, possibly at the next meeting. He was glad the curve on page 104 had been confirmed by their own work unintentionally and in a different way. The diagram was quite inexplicable unless there was an inversion or critical point at about 450° C. It was intelligible if that was admitted. Mr. Bengough had asked speakers to give their views with regard to Fig. 3. It was quite clear that at about 400° to 405° , as the temperature increased, a structural change took place, exactly as they would expect if there was an inversion. At 500° C., just above that point, the crystals had taken a new form. That again was a point bearing out the view that there was an inversion in the α constituent. When they brought forward their paper they hoped not only to deal with the inversion, but to throw some light on the nature of the α constituent in the brass.

Professor TURNER, M.Sc., Honorary Treasurer, remarked that they were very much indebted to the authors for the further contribution they had given to a very important subject. Their previous papers had been of great use to those interested in the working of brass. That paper threw a good deal of light on what they had called elsewhere "mechanism of annealing." They had to consider two separate matters in connection with the heating of brass as the authors had shown them, namely, the question of ordinary annealing and the question of burning. The latter, as the authors had shown, was not due to oxidation. He thought that the experiments in a reducing atmosphere were conclusive upon that point. They had also shown that it was not due to the volatilisation of one constituent, although they had observed a certain amount of volatilisation of zinc on the exterior of their bars. Professor Carpenter had already indicated what appeared to him to be the most probable explanation of what was called "burning," namely, that there must be a certain amount of separation of fusible constituent leading ultimately to the formation of those distinct boundaries of the crystal masses. That constituent was brittle, and the result was that even if they had a very small separation of constituents of a brittle character, the grains would readily separate. In the case of steel, under the microscope, the burning effect was perfectly obvious. They had a separation of material richer in carbon in which they had, say, sulphide of manganese or other materials separated and perfectly visible to the eye. It appeared reason-

able to suppose that the burning effects observed in those alloys were of similar character to what were observed in steel. To produce the effect they had merely to give time, at a sufficiently high temperature, for some of the constituents to gradually separate and collect in the borders of the masses of a somewhat purer material. Turning to the question of annealing of pure material, that was one of the greatest mysteries of metallurgy at the present time. They took a metal which had a certain definite tensile strength in the cast state. That tensile strength would be roughly, at all events, determined if they knew the atomic weight of the metal and its density. In other words, all metals in the cast state have a tenacity which varies with the atomic volume. If they increased the number of the molecules in a given space they increased the tenacity, and *vice versa*. They knew the tenacity of the material if they knew its atomic value. By rolling in the cold state it became very slightly more dense, and they got what was called "worked-hard" metal. The rolling of that metal, however, made an almost infinitesimal difference in the atomic volume. By drawing, it was slightly reduced in density, and it was also made hard. It might be said that a strain had been set up, but that did not explain the matter. The question presented to the metallurgists was, why did that minute alteration in the molecular distances make the material into what was for all practical purposes an entirely new metal? The difference between rolled aluminium and cast aluminium was so great that they were distinct and separate metals, more distinct even than tin and lead. Their physical friends might direct their attention to the solution of that problem, which was one of extreme suggestiveness. Their meeting that morning would be memorable from the fact that Dr. Carpenter had announced the recognition of an inversion in the copper-zinc series. They had taken Shepherd's diagram as the basis in connection with observations on the copper-zinc series for some years past, and they had in the authors' paper an inversion shown from the mechanical point of view. Dr. Carpenter had now announced that he had observed that inversion, and he could recognise it from the physical point of view. They would look forward to his paper with very much interest.

Mr. R. M. SHEPPARD (Birmingham) said he had been very interested in the paper, but there was one point not dealt with which he rather wished had been there, namely, the effect of quenching 70 : 30 metal after annealing. He thought if Messrs. Bengough and Hudson were experimenting further with those brasses, some test carried out on the quenching of samples would be extremely interesting, especially to manufacturers. Personally, he had made some tests with some quenched specimens, but had not time to do as many as he could have wished. He only worked on one temperature. They were 70 : 30 tubes annealed at a temperature of about 650° to 680° C. One of those bars was allowed to cool down slowly, and the second one was withdrawn from the furnace and immediately quenched. The third one was allowed to cool down to about 350° and then quenched. The one quenched first showed

the highest elongation; the one quenched at a black heat showed the second best elongation; and the one allowed to cool slowly showed the worst. The figures were 64, 66, and 67 per cent. The tensile strength was practically unaltered, being slightly higher with the one quenched at a black heat, and varied from $21\frac{3}{4}$ tons to the square inch to $22\frac{1}{4}$ tons. With regard to the analysis of the bars given at the beginning of the paper, it would be noticed that bar HB was purer than bar G, and they noticed a great deal of difference in the figures for the bars as rolled and as set forth in the Tables II. and III. He did not know whether Mr. Bengough could say if there was any difference in the rolling treatment of those two bars. It would be interesting to know what it was. It might be that the results obtained in the tests were due to the purity of the bars. From the tensile tests and microstructure bar G appeared to be already partially annealed, being similar to bar HB after annealing at 630°C . for half-an-hour, as shown in Fig. 6; though the tensile test figures for the two are rather different, the elongation of HB3 being very much higher. He would like to ask Mr. Bengough if he could tell them whether that was due to the impurities of the one, or to the difference in the method of rolling.

Dr. C. H. DESCH (Glasgow) said they must regard the paper as an exceedingly valuable specimen of a class of very great importance to the Institute, containing a series of systematic tests of the influence of heat-treatment on quite definite alloys. He noted that the authors quoted a suggestion from something he himself had written that the burning of brass was primarily due to the volatilisation of zinc from the α -solid solution. That was a suggestion which he put forward tentatively as the result of examining brass specimens under different conditions. He did not wish to be in the least dogmatic, and if he had been disposed to dogmatise on brass any rashness of that sort would have been cured after what Sir Gerard Muntz had told him on the subject. He thought volatilisation from the solid solution must play a part in what was called the burning of brass. There were different ideas as to what actually constituted burning, but a typical burnt specimen showed signs of volatilisation, not necessarily causing a loss of zinc from the whole mass, but indicating a loosening of the molecular structure. They found that pitting took place more readily in burnt specimens, and that suggested a loosening of molecular structure of which the volatilisation was perhaps only a symptom. With regard to the behaviour of metals subjected to stress at high temperatures, the curve on page 104 was exceedingly interesting. He was glad they had conducted such tests. They had only been using small bars, and perhaps if they got apparatus for testing full-sized bars, the result might be still better. The remarkable recovery of ductility at certain high temperatures was characteristic of copper-zinc alloys, not only of brass, but of manganese bronze as well. He was greatly interested in what Professor Carpenter had said, and had long been of opinion that some critical change took place in copper-zinc alloys at about the temperature indicated. He had been inclined to

think there was something in the line shown on Roberts-Austen's diagram. He was greatly interested to know that it had now been detected pyrometrically, and if it was true that there was evidence of another micrographic constituent, that was a very interesting matter. He could hardly imagine that the new constituent was identical with the β -solution, and if it should be a different one it would lead to a most revolutionary change in Shepherd's diagram.

Mr. F. JOHNSON, M.Sc. (Birmingham), said he feared that some of his remarks had been anticipated by previous speakers. He had wished to refer especially to the volatilisation of zinc. As to Mr. Sheppard's remarks, the point that interested himself was the statement that the quenched alloy was more ductile than either of the others. That was a very important point, proving that the usual workshop practice of quenching after annealing was warranted not only in economy of time but in improvement of the ductility of the material. They had but to glance at the number of tables compiled by the authors to realise the vast amount of work they had accomplished. But a greater insight into the text and a careful study of the diagrams and tables were necessary to appreciate the great and lasting usefulness of that work. To the manufacturer it must be a great boon to have a ready and facile means of recognising exactly what results he might expect from heat-treatment at specified temperatures, and what dangers lay in his way in the matter of over-annealing. To the user also the ability to realise the limitations of such material must be a big asset. For example, Fig 4 on page 97 showed very graphically that 70:30 brass could not be expected to retain its original strength and properties if used in situations where the temperature would reach 300°C . As regarded the loss of zinc by volatilisation, that was a very interesting discovery, and left them wondering what the structure of those surface layers of the alloy must be, after the loss of part of one of its constituents. Was that a question of equilibrium readjustment, and was the ultimate result a solid solution of zinc in copper of a lower degree of concentration than before? It was an interesting speculation as to how this action would continue, and where it would end if sufficient time were allowed. Would the volatilising action extend right to the core, and if so would there be from the centre a continuous diffusive reinforcement of those zinc molecules lost at the surface? It was conceivable that the higher the percentage of zinc contained in the alloy, the greater the velocity of such an action, and that eventually a degree of concentration would be reached where volatilisation would cease. What then would be the physical condition of the α phase? Would it possess greater or less density than before? With regard to tests at high temperatures, he was particularly interested in these, as such tests were likely to prove of great value. Owing to the great heat conductivity of brass, would it not be a difficult matter to maintain the temperature constant over the whole length of the specimen? The authors had not stated if the suspending clamp and stirrup were insulated in any way. As regarded burning, metal which had

been affected merely by being raised to too high a temperature should, he (Mr. Johnson) thought, be described as overheated, and metal which had been maintained at the annealing temperature for too long a time should be described as over-annealed, and he should prefer to describe as "burnt" a metal upon which the naked flame from the burning fuel, as in open types of annealing furnace, had been allowed to impinge. This would cause an intense local overheating effect, accompanied possibly by inter-crystalline fusion. The effect might be only superficial, but a crack or flaw once started, especially when accompanied by the inter-crystalline fusion product, would develop seriously when the material was submitted to subsequent mechanical work. His last point was a practical one. He would like to ask the authors if they had any knowledge how to detect overheated or over-annealed material after it had been subjected to mechanical treatment subsequent to the injurious heat-treatment. Would not all evidence in the way of enlargement of crystals be destroyed? That was an important point, because more often than not a metallographical examination has to be made upon metal which may have received injury during a stage considerably antecedent to that stage at which such injury revealed itself. The evidence of the microscope might then be misleading, if, as he had reason to believe, a structure, tell-tale in its original coarseness, had been refined by a subsequent stage of mechanical work and heat-treatment so as to possess no distinguishing difference from normally treated metal which had gone through the same stages. He wished, in conclusion, to express great appreciation of the paper, and to express the hope that it would not be the last by a great many which they would receive from its distinguished authors.

Mr. J. J. EDWARDS (Woolwich) said that the discussion had been carried on, so far, by metallurgical experts, and perhaps a few words from the workshop might now be welcome. He personally dealt somewhat largely with 70:30 brass strip: and annealing—the prominent point in this paper—claimed much of his attention. He considered that 650° C. was an ideal temperature to use for annealing this type of brass. Satisfactory annealing could, however, be carried out with a higher furnace temperature, provided arrangements were such as to ensure that the metal to be annealed would only be exposed to the furnace temperature for the time necessary to impart the desired extent of annealing. The time would be determined by trial, and would vary with the thickness or bulk of the metal to be annealed. He preferred furnaces in which the time of the exposure of the brass to heat is automatically controlled. They should realise that "burning" or "over-annealing" does not result from too high temperature of furnace only, or from too long exposure of the brass to the temperature only: but rather from both these factors—time of exposure and temperature of furnace—working together. Brass may be raised to 800° C. and maintained at that temperature for a considerable time—say twenty minutes for strip 0.15 inch thickness—without appreciable harm, if there be an absence of vibration or rough treatment during the heating and cooling of the metal. If the time were doubled, tem-

perature remaining at 800° C., the result would be a slight reduction of tensile strength and a small increase in percentage of elongation obtainable from a test-piece. He did not, however, advocate annealing temperatures higher than 650° C. plus and minus 50° . These limits were both practicable and safe. He favoured the regular daily use of the microscope in the works, so as to check and as far as possible ensure regularity of annealing and uniformity of output. A magnification of about 36 diameters was, he considered, suitable for this purpose. While it was possible to make actual measurements, under the microscope, of crystals in etched specimens of brass, he did not consider that this was either necessary or desirable: for visual comparisons of structure, as seen under the microscope, could be made quickly, and reliable data obtained in practice. Etched specimens, representing the desired degree of annealing, with permissible limits, should be set aside for reference when required, but persons who are in daily touch with the examination of brass microscopically, could readily detect, visually, even slight variations in the crystalline structure. With regard to the removal of zinc from brass by oxidation during the time of exposure to heat in the annealing furnace, this could only be surface action, and would not appreciably alter the composition of the brass. He suggested that experiments with brass made from the purest brands of electrolytic copper and zinc, in comparison with that made from raw materials containing appreciable amounts of metals other than copper and zinc—such as iron, lead, antimony, bismuth, and arsenic—would be instructive. Personally, he preferred the purest copper and zinc as constituents of 70 : 30 brass.

In conclusion, he desired to express the indebtedness of manufacturers to the authors for their excellent paper. It threw light upon a matter of much importance in workshop practice, and its preparation must have entailed a large amount of work.

Mr. H. H. A. GREER (Glasgow) said that he wished to thank, on behalf of the manufacturers at Glasgow, the authors for giving them that very interesting paper. He felt how much they were indebted from the manufacturing point of view for the words they had just heard. He was wondering when the authors were speaking about burnt metal whether that was exactly what they recognised in Glasgow as burnt metal, such as, for example, in the gun-metal or tin alloys when melted. They had always looked upon burnt metal very largely as oxidation. He was wondering in regard to the annealing of tubes and brasswork if that was the same thing, and if they could give any idea in the case of tubes or brass burnt in annealing how it would be brought back to the original condition. If so, they would be very glad to know that. It was a point that manufacturers had to study, and if a workman made a mistake in annealing it would be very useful to know how to bring the metal back again to its proper condition.

The PRESIDENT said he was not going to call upon any more gentlemen to join in the discussion, because he thought they had got enough to go on with, and any gentleman who had a further contribution to make might make it in writing. The authors in their concluding remarks appeared to suggest that they had finished their work. He did not know whether that was how they felt, but his idea was that they were only just beginning their work, and he hoped they would not give it up under the idea that it was finished, and if they imagined that they had spent sufficient time on it there was a great deal yet to be done by any gentleman who might follow them. Personally, he was a workshop man, and as such he had a knowledge of materials from their primary condition until they developed into finished articles, and that paper, to him, had been one of extraordinary interest. It was not with him a question of knowing what to say, but of knowing where to leave off, and therefore he was not going to attempt a criticism of the paper. He was extremely interested in Dr. Carpenter's remarks with regard to the curve of the authors', showing a change in the nature of the materials at about 400° . Speaking from practical experience he had no doubt that a change of that nature did take place in brass at about that temperature, the result of which had been in the past many strange little happenings in manufactories which had been to a certain extent inexplicable. He thought to a large extent, owing to the work of that Institute, manufacturers were now able to trace, possibly, the cause of many of those troubles. There was another point, as to what was burnt brass, and Mr. Bengough had been invited to say what he considered to be burnt brass. His own impression was that the authors had not yet reached burnt brass. They had never got burnt brass, but merely over-annealed brass. They had just been asked what to do to restore burnt metal. There was only one thing to be done with it: to put it in the melting pot and melt it up again. Burnt brass was something they could do nothing with. Mr. Johnson had suggested that it was possible to be misled by the effect of the mechanical treatment of overheated metal. That was impossible, because they could not put any work on burnt brass, and they might give it up as a bad job, because it would fall to pieces and could not be worked. If they over-annealed 70:30 brass to the degree of burning, they might pick up one end of it, and it would fall to pieces on the floor. That is what he would call burnt brass. Obviously, the only thing to do was to put it in the melting pot. They got that sometimes in works practice, though not often. Another point he would suggest with regard to the length of time for annealing. He thought some of his colleagues who were practical manufacturers, regarded those experiments as rather outside practical operations. It had been suggested that annealing might go on for two or three hours, or a day or two, but manufacturers had not time for such lengthy annealing. With regard to the question of temperature, a maximum of 930° was given. Apparently the maximum had not been attained, and he thought that if they went over 930° , they would get some remarkable micrographs. Dr. Carpenter said that there was a change at a temperature of 450° and probable changes

at higher temperatures. There was certainly room for greater investigation there. In works practice it was desirable to work to a given temperature, and graduate the time of annealing. Changes of temperature could be effected scientifically in the laboratory. Such changes could not be carried out in the works. The workman simply could not do it, and works practice had to be carried out by means of the instinct of the men. If they had a higher temperature for a shorter time, and a lower temperature for a longer time, they arrived at the same results within reasonable limits. He could go on talking for a considerable time, if time permitted. But they would get more interesting remarks in written contributions later on.

MR. O. F. HUDSON, M.Sc., replying, said he wished to express his pleasure at the encouraging way the paper had been discussed, but that as so many points had been raised he feared it would be impossible to deal with all of them now. They proposed, however, to reply more fully in writing. It was extremely interesting to hear that Professor Carpenter had been able to confirm the existence of the inversion at about 400°C . which had been observed by Roberts-Austen in the copper-zinc alloys. Their own results seemed to point to a constitutional change in 70 : 30 brass in the neighbourhood of that temperature. Dr. Carpenter had inquired whether they had found any β constituent on examining the microstructure. They found no sign of any β constituent even in those bars which they had described as burnt, but he was ready to believe that they had not succeeded in producing any burnt brass, as that term was understood by manufacturers. He would like to point out that brass that had been over-annealed could be readily worked afterwards. He had a sample of brass wire which had been drawn out quite satisfactorily from brass annealed for half-an-hour at over 900°C . The wire apparently was just as good in character as the original alloy, but how far the effect of over-annealing persisted had not been dealt with in the paper. The question of the handling of brass at high temperatures had been raised by other members in the course of the discussion. If they would refer to the paper they would find that one suggestion put forward was that serious injuries were likely to result if 70 : 30 brass was roughly handled or subjected to any shock when hot. As one member had pointed out, if it was subjected to vibration while at a high temperature it was very likely that injury would occur. Brass was ordinarily quite brittle at about 400°C ., and although it regained a large measure of its ductility at a somewhat higher temperature, as the temperature was raised still higher the tensile strength decreased to a very low figure.

COMMUNICATIONS.

MR. T. VAUGHAN HUGHES, Assoc. R.S.M. (Birmingham), wrote that Messrs. Bengough and Hudson's paper was full of interesting matter; interesting, because the results of their work were put concisely before

members. At the same time he thought that it would not be out of place if he were allowed to state that a research of the kind undertaken by the authors had, to his knowledge, been accomplished at least ten years ago by more than one Midland firm. True, it was done more or less intermittently. The main facts narrated in the authors' paper, however, had, he believed, been fairly well known to the manufacturers of cartridge metal for many years.

In appreciating the value of the results contained in that paper, it was well to remember that the alloy had been heated in an atmosphere which was not at all identical with that normally present in the usual works annealing furnace. Stress must be laid on this point, because the authors laid much weight on the results of annealing in so-called reducing gases. They stated on page 101 of their paper: "It seems probable that the presence of reducing gases is at any rate not a predominant factor in the production of burnt brass, since annealing in an oxidising atmosphere produces very similar effects." They reiterated this on page 107, paragraph 4: "It has been shown that the atmosphere of the annealing furnace, whether oxidising or reducing, does not appear to affect in any well-marked manner the properties of brass."

Had they really been annealing in an oxidising atmosphere? Rather had they not been annealing in an atmosphere largely composed of nitrogen in which the oxygen may have been removed wholly or in part by combination with the occluded gases evolved from the metal when heated in presumably a closed tube and partially by combination with the zinc of the alloy. Unless they had as check a pressure indicator attached to the apparatus, the whole of the muffle atmosphere might have been replaced by occluded gases from the test-pieces.

Then again, they did not give the composition of the coal gas employed. It did not by any means follow that in so far as brass was concerned substitution of the contained air in a small muffle by coal gas produced a reducing atmosphere. They might easily prove the value of this criticism, however, by making an attempt to estimate zinc by Lowe's method (described some years ago in the *Journal of the Society of Chemical Industry*), employing the town gas as a reducing atmosphere. He (Mr. Hughes) used that method of estimating zinc in Chester with considerable success for some years. He failed completely, however, to obtain concordant results when using Birmingham coal gas, and was obliged to employ other gases.

An analysis of the coal gas the authors employed in displacing the air in a very small muffle would give members some desirable information. The employment of coal gas as an atmosphere for annealing metals had been the subject-matter of more than one patent, beginning as far as he could ascertain from the year 1870 downwards.

With reference to Professor Carpenter's discovery of a new critical temperature in brass at about 450°C ., he could confirm that, having ascertained it in the year 1904 by a modification of the Roberts-Austen recorder. Circumstances prevented the writer from increasing the sensitiveness of his research pyrometer, because it appeared to him at

the time that the critical change began at about 290° C. to 300° C.—a temperature at which zinc appeared to have sufficient vapour tension to alloy with the clean surfaces of most metals with which it might be in contact. Was the mobility of the constituent of a solid solution due to the vapour tension of a number of those constituents permitting, as it were, a progressive movement on a layer of gaseous metal?

Again, might not the attention of members be directed to the fact that no determination of the zinc was given in any of the alloys. In research work of the character undertaken by the authors he submitted that a full analysis should be made, although the existing methods of determining zinc were not as accurate as they might be. Nothing should be taken for granted.

In spite of all that had been done a definition of “burnt brass” was still wanting.

It had been the practice of casters of best brass to allow their freshly cast ingots to cool below visible red heat before attempting to fracture “off” the “get ends.” At this temperature the ingots were fragile; above and below generally tough. The authors’ work had a bearing on this practice.

Mr. F. JOHNSON, M.Sc. (Birmingham), referring to his remarks made at Glasgow on the subject of identifying the causes of failure of metal during the process of manufacture, wrote that he would again like to draw attention to the difficulties which lay in the way of the investigator. Before doing so, he wished, in order to correct the impression which the President received from his remarks, to state that they did not refer to “burnt” metal at all. Obviously “burnt” metal required no scientific aid to detect its condition. His remarks applied only to metal which had been over-heated or over-annealed, or, possibly, injured by rough handling; and he wished to indicate how difficult it was to employ the microscope with a view to ascertaining the cause of failure, if the material had had work put upon it subsequent to the injurious treatment. That was particularly true in the case of copper which may have been forged at slightly too high a temperature. An incipient crack formed during that process might not be noticed until cold-working had developed it. How was it, then, to be said with certainty when and in what manner the flaw occurred? It was extremely doubtful if the microscope would be of any assistance.

Messrs. BENGOUGH and HUDSON wrote, in further reply to Professor Carpenter, that in brass lower in copper than 70 : 30 the β constituent did undoubtedly separate at high temperatures and was quite possibly the cause of burning in such alloys. In the authors’ bars, however, no β separated at high annealing temperatures. The authors were much interested to hear of Professor Carpenter’s experimental evidence to show that an inversion took place in brass alloys of this type at about 450° C. The point had probably considerable industrial importance.

The authors would like to thank Professor Turner for his appreciative and interesting contribution to the discussion.

The authors were much interested in the experiments on the tensile strength of quenched 70 : 30 brass, quoted by Mr. Sheppard. They were inclined to agree that quenching might give a slightly higher elongation, and this was probably connected with the inversion already referred to by Dr. Carpenter. With regard to the difference between the bars G and HB, the latter certainly had received more work than the former, and the difference in microstructure between the two bars, as rolled, is to be attributed mainly to this circumstance. The difference in the quantities of impurities in the two bars would have comparatively little effect on size of structure.

In reply to Dr. C. H. Desch, the authors considered that so far as their own bars were concerned, loss of zinc by volatilisation had no very great effect on the deterioration of mechanical properties. They had been told at the meeting that none of their bars had been really "burnt" in the manufacturers' sense of the word, but were merely severely over-annealed. They were, therefore, unable to say whether the explanation put forward by Dr. Desch might or might not apply in such cases.

Replying to Mr. Johnson, the authors valued his remarks on the questions of volatilisation of zinc and the after-effects of over-annealing. They were of opinion that volatilisation occurred at the surface of the alloy, and that diffusion of zinc took place from the centre outwards. The ultimate effect of over-annealing was a question that was worthy of further research.

The authors were much interested to hear Mr. Edwards' views on workshop practice of annealing, and were gratified to learn that manufacturers found their paper of interest. The authors were in agreement with the points raised by Mr. Edwards in his remarks.

The authors thanked Mr. Greer for his appreciative remarks. With regard to his observations on the burning of gun-metal and tin alloys, the authors were not at present prepared to say whether that was due to oxidation or not. As to the question of restoring burnt or oxidised metal, the only satisfactory method was remelting.

In reply to the President, one of the authors had already indicated that they had by no means solved all the problems in connection with this alloy, but that they had merely completed their original scheme of work which they hoped in the future to use as the basis for further investigation.

With regard to the President's question as to what the authors considered to be burnt brass, they were not prepared to give a definition which would apply to the material produced by manufacturers. With the limited resources at their disposal they had been quite unable to produce the advanced degree of ruin that had been so graphically described by the President. They would be glad to have specimens of this material, if any could be rescued from the fatal fascination of the crucible! With regard to the time of annealing adopted by the authors, they would point out that the majority of the experiments were carried out for a period of half-an-hour, which period is not widely different from that adopted in works practice. The few experiments that were

carried on for longer times were intended merely for comparison with those under standard conditions. The authors would point out that at the maximum annealing temperatures adopted they had carried the annealing up to the point of incipient fusion.

In reply to Mr. Vaughan Hughes, the annealings in an oxidising atmosphere were carried out in electrically heated tube furnaces, 12 inches long and $1\frac{1}{8}$ inch in diameter. The ends of the tubes were closed by very loosely packed asbestos fibre, and there was no reason to suppose that there was not sufficient diffusion through the asbestos plugs to render the atmosphere distinctly oxidising. Liverpool coal gas was used to give the reducing atmosphere, the test-bars being placed in a porcelain tube, through which a continuous stream of gas was passed; this gas was burnt in a Bunsen burner after it had passed through the tube, the atmosphere of which must have been strongly reducing. That the annealing conditions were quite different was shown by the heavy scaling of the bars in the one case and the entire absence of scale in the other. The analyses of zinc in the bars were given at the meeting.

SHRINKAGE OF THE ANTIMONY-LEAD ALLOYS

AND OF THE ALUMINIUM-ZINC ALLOYS DURING AND AFTER SOLIDIFICATION.

By DONALD EWEN, M.Sc., AND PROFESSOR T. TURNER, M.Sc.

INTRODUCTION.

By PROFESSOR TURNER.

THE work done by Mr. Ewen is an extension of that already published in conjunction with Mr. M. T. Murray, on the copper-zinc series of alloys.* The general method of procedure has been the same as before, the changes of length of a cast bar being observed, by means of an extensometer, from the moment of solidification down to the ordinary temperature. To this method of investigation exception has been taken by some who have been good enough to criticise the work, on the ground that the measurements do not give volume changes, but only alterations in length. It has been suggested that, in the case of a cast bar, owing to crystal thrust or other causes, the volume may vary in a different proportion to the length. No experimental proof has, however, been adduced in support of the above suggestion, while there is direct evidence that in certain cases an increase of length of the cast bar does coincide with a diminution in density. Probably the normal case is that where the bar decreases in length it increases in density, and *vice versa*, and though it is possible, or even probable, that certain more or less abnormal cases may be found to exist, these exceptions will not in any way detract from the value of the extensometer as a simple and trustworthy indicator of internal changes which are not readily observed by other methods. From the practical standpoint also the study of the behaviour of cast bars is of great importance, since the number of articles cast with three

* *Journal of the Institute of Metals*, 1909, vol. ii. p. 98.

equal dimensions is almost negligible, and all other shapes approach more or less nearly to the bar form.

When the extensometer was first applied to the study of the cooling of cast bars the whole field was open to investigation, and typical substances at once yielded very interesting results. In natural sequence came the study of series of alloys, and accumulating observations show that the subject is by no means so simple as might be at first anticipated. It may perhaps be well here to consider under which conditions a change of volume may be expected to result when substances are subjected to changes of temperature.

1. When chemical union takes place there is usually a marked volume change. This is generally in the direction of "close-packing," and leads to smaller volume, as, for example, when carbon or hydrogen unite with oxygen. But, exceptionally, chemical union may result in largely increased volumes, as with explosives; these latter cases are often capable of being regarded as being the formation of simpler from complex types, and are thus, perhaps, less contrary to rule than they at first appear.

2. There is usually a marked volume change noted when an allotropic or dimorphic transformation occurs.

3. There is a change of volume when one substance dissolves in another, and conversely when a body separates from solution there is a corresponding change in the opposite direction. As a rule, dissolution is accompanied by contraction, and separation or crystallisation by expansion. There are, however, notable exceptions to this general rule, as, for example, with the ammonium salts, which expand on dissolving. Dissociation is believed to account for some special cases, while hydration and ionisation doubtless play their part in other instances.

4. The separation of constituents which occurs during the solidification of a eutectic appears usually to be accompanied by a measurable expansion.

In the work of Mr. Murray on the copper-zinc series of alloys it was shown that where a continuous succession of solid solutions separate out, the extensometer curve closely follows the solidus. Mr. Ewen has now shown that in the

antimony-lead alloys, where no solid solutions exist, the extensometer curves give negative results, no single bar of the series having expanded more than the original antimony. The expansion due to the solidification of the eutectic has, however, been noted. In the aluminium-zinc series, on the other hand, where solid solutions exist, Mr. Ewen has found that the expansion curve closely follows the liquidus curve from 0 to 50 per cent. of aluminium, when allowance is made for the expansion noted at the eutectic point.

Side by side with Mr. Ewen's researches, experiments have been in progress with various alloys of iron, and these have given interesting results, which are in course of publication elsewhere. It is hoped that by extended study on systematic lines the important points which are still undetermined may be made clear, and further information obtained which may be of interest to the metallurgist and physicist.

SHRINKAGE OF THE ANTIMONY-LEAD ALLOYS AND OF THE ALUMINIUM-ZINC ALLOYS DURING AND AFTER SOLIDIFICATION.

BY DONALD EWEN, M.Sc. (Birmingham).

OBJECTS OF THE RESEARCH.

The importance of the volume changes of metals during and after solidification is gaining more recognition year by year, and by the present research it is hoped that a little more light will be thrown on so interesting a subject, which, however, seems to grow more complex the further it is investigated. The attention which the volume changes of metals and alloys are attracting in the metallurgical world is shown by the number of researches which have been published lately on this subject.

Total shrinkage has also received a fair share of notice, though it imperfectly indicates the value of a given material for casting

purposes, since it gives only the algebraic sum of the volume changes after casting, whereas the nature and rate of shrinkage are also important when the casting properties of a metal are under consideration.

In the recent researches of Wüst (¹) on the shrinkage of metals and alloys, volume changes were measured with an extensometer of novel design, the motion of two pins, one at each end of the test bar, being conveyed to a graduated capillary tube by hydraulic pressure by means of cylinders, pistons, and connecting pipes. With this instrument a large number of metals and alloys were tested, and to some of the results reference will be made later.

Degens (²), working on the tin-lead alloys, measured volume changes in a modified form of dilatometer, which appears to be quite satisfactory for alloys of low melting point. His results, however, can hardly have so great a technical value as those obtained by Wüst, and still earlier by Turner (³) and by Keep (⁴), where the test bars were cast in sand moulds, so that the conditions of casting and cooling approximated closely to those obtaining in actual practice.

M. T. Murray (⁵), a former Bowen research scholar of this University, has investigated the volume changes of the copper-zinc alloys during solidification, and has suggested the possibility of plotting the solidus curve on the equilibrium diagram of these alloys by means of the amounts of expansion shown on solidification which are in proportion to the distances between the solidus and liquidus for all alloys containing above 40 per cent. copper.

This theory having been started in connection with the brasses, it was thought that its applicability to other series of alloys should be tested.

PART I.—THE ANTIMONY-LEAD ALLOYS.

Some preliminary shrinkage curves of these metals and alloys having been obtained by Murray, it was decided to begin with the investigation of this series.

Wüst (¹) has determined the shrinkage curves of the pure

metals, antimony and lead, but otherwise no records of previous work on this subject are to be found.

Lead-antimony alloys are of considerable commercial importance, being employed for the production of white metal bearing linings, and for type metals. Small proportions of antimony are also added to lead for hardening purposes, as in the production of leaden bullets.

PREPARATION OF THE ALLOYS.

The metals used were the purest obtainable. The lead was guaranteed to contain 99.95 per cent. of lead, with traces only of bismuth, iron, zinc, and antimony, whilst the antimony was guaranteed 99.5 per cent. pure. A sufficient quantity of both of these metals was kindly presented by Messrs. Cookson of Newcastle-on-Tyne.

In making up the alloys the exact percentage required was weighed out, no allowance being made for loss of antimony, this procedure being justified by subsequent analysis. The antimony was first melted in a covered fireclay crucible (Morgan's H size) over a small coke fire; the requisite amount of lead was added, the alloy well stirred, and the bar cast.

APPARATUS USED.

The method of experimenting and the apparatus used for observing the alterations in length of this series of alloys were the same as those employed by Turner and Murray (⁵) in their work on the copper-zinc alloys.

The apparatus consisted of, first, the sand mould in which the test bar was cast; secondly, the extensometer for measuring the changes of length; and thirdly, the pyrometer which recorded the changes of temperature (⁵).

Owing to the small size of the test bars, namely, half-inch square section, cooling was too rapid to give very satisfactory cooling curves, but the eutectic halt was obtained with all the alloys, and it averaged 228° C., being thus in agreement with the result obtained by Roland-Gosselin (⁶).

Assay of the Bars.—Having been cast, the bars were sampled

by drilling at six different points, and assayed. The scheme of analysis as first drawn up involved a volumetric estimation of the antimony by means of potassium iodide (⁷). After repeated trials this method was discarded, and the lead was estimated gravimetrically as sulphate, the analysis being standardised by running a couple of assays on the pure lead bar.

Rapid solution of the samples was obtained by using a mixture of nitric acid with a concentrated solution of tartaric acid. The antimony was estimated by difference. The results of the analysis are given in Table I.

TABLE I.

Bar.	Lead by Assay.	Antimony.	Expansion (in inches) on 12 Inches.	Remarks.
	Per Cent.	Per Cent.		
I. . .	...	100.0	.0025	...
XI. . .	12.3	87.7	.0020	Gate slightly piped.
II. . .	22.5	77.5	.0020	Much piped gate.
X. . .	31.6	68.4	.0019	Gate slightly piped.
III. . .	42.9	57.1	.0000	" " "
IX. . .	51.2	48.8	.0015	" " "
IV. . .	62.8	37.2	.0000	...
VIII. . .	76.8	23.2	.0006	...
V. . .	85.4	14.6	.0012	...
VI. . .	94.9	5.1	.0011	...
VII. . .	100.0	...	.0000	Not piped.

The nature of the piping of the gates of this series of bars was unfortunately not noted in every case, and as many of the original bars were used up in subsequent trials when using a heated iron mould (to obtain slower cooling), such observations were afterwards rendered impossible. So far as could be judged, the piping was largest when the casting temperature was nearest to the commencement of solidification. It will be observed from the cooling curves that towards the antimony end of the series the heat of surfusion is very pronounced.

SHRINKAGE OF THE ANTIMONY-LEAD ALLOYS.

Whilst no expansion was observed in the shrinkage curve of pure lead, pure antimony expands to a considerable extent. These results confirm those obtained by Murray (⁵), and

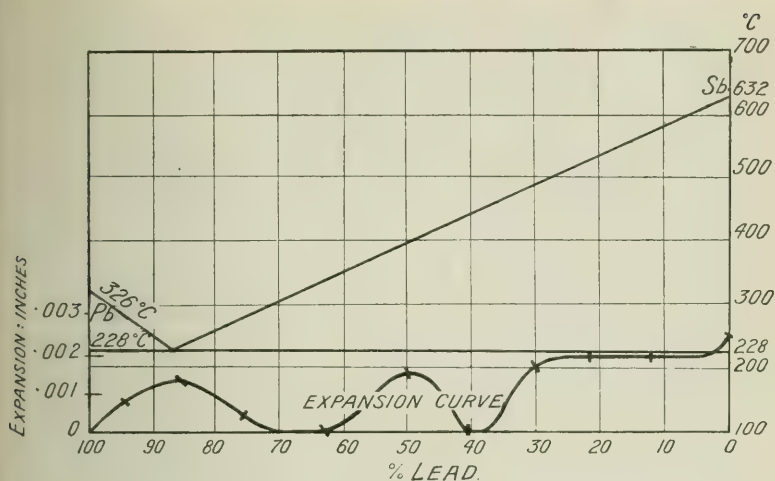
similar values were obtained later when using the mirror extensometer employed in investigating the aluminium-zinc alloys. Wüst (¹), however, has stated that neither pure lead nor pure antimony expand on freezing, but no particulars are supplied as to the purity of the materials employed. The equilibrium diagram of the antimony-lead alloys has been worked out by Roland-Gosselin (⁶) (Fig. 1), and indicates the total insolubility of the two metals in the solid state, the eutectic halt being present in the cooling curves of all combinations of these metals. The eutectic alloy contains 13 per cent. antimony, and melts at 228° C. All alloys containing less than 13 per cent. antimony consists of primary lead crystals in a matrix of eutectic; with more than 13 per cent. antimony the alloys show primary antimony crystals surrounded by eutectic. Thus the microstructure of the series is very simple.

The shrinkage curves are less easy of explanation. It should be said that the first reading of the extensometer was taken immediately the gate was full of metal. This reading was taken as the zero for the shrinkage curve, so that the changes recorded in this research are due to the behaviour of the bar itself after casting, and cannot be ascribed to the mechanical influences of casting, such as wash of metal or jarring. This being so, it is believed that the values obtained represent actual expansion.

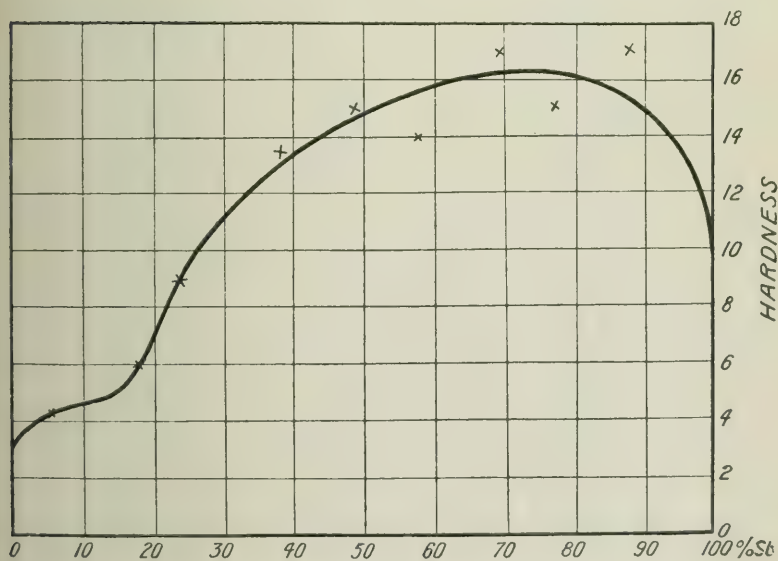
The cooling and shrinkage curves obtained are shown in Fig. 5; only the earlier parts of the extensometer curves being shown (in the upper part of the diagram), as contraction was perfectly uniform after the first few minutes.

Pure lead shows no expansion. On making increasing additions of antimony the expansion increases to a maximum at about the eutectic composition, with 13 per cent. antimony; it then falls to a minimum at about 35 per cent. antimony, whence it rises to a second maximum at about 50 per cent., and, after falling again to 60 per cent. antimony, it increases gradually up to that of pure antimony. These results are summarised in the expansion curve (Fig. 1).

According to Wüst (¹), melts of about eutectic composition show a minimum of shrinkage, which observation serves as



Equilibrium Diagram of Antimony-lead Alloys (Roland-Gosselin).



Hardness of Antimony-lead Alloys.

FIG. 1.

indirect confirmation of the expansion maximum noticed at this point. It is not so easy from the equilibrium diagram to account for the maximum found at 50 per cent. of antimony in conjunction with the minima at 35 per cent. and 57 per cent. It should be noticed, however, in this connection that although Bar III. (57.1 per cent. antimony) and Bar IV. (37.2 per cent.) were both cast at a slightly higher temperature than Bar IX. (48.8 per cent.), they show a much more coarsely crystalline and dendritic structure than the 48.8 per cent. bar. in which small white primary crystals of antimony are very uniformly distributed throughout the section. Possibly, then, this is an example of expansion due to an altered form or method of crystallisation.

Beyond 57 per cent. antimony the expansion curve rises rapidly at first, and then more slowly up to the highest expansion of the series given by pure antimony, the influence of the antimony on the expansion gradually asserting itself in a more or less normal fashion.

Considering this expansion curve in its relation to the distance of the solidus from the liquidus in the equilibrium diagram, the results are purely negative; a relatively large expansion is obtained at 13 per cent. antimony where solidus and liquidus meet, and from this point to pure antimony, while the distance between the solidus and the liquidus is uniformly increasing, the expansions vary from zero through a maximum to zero again and thence up to pure antimony. The experiments of Murray, to which previous reference has been made, were conducted on the copper-zinc alloys, which exhibit a series of solid solutions, whereas antimony and lead are mutually insoluble in each other. Possibly the close relation between expansion and range of temperature during solidification may hold only for alloys of metals which are more or less soluble in each other in the solid state. It would appear that the rule does not obtain in the case of metals which form no solid solutions if the antimony-lead series may be taken as typical of such.

HARDNESS.

It was thought that hardness tests might help to explain the somewhat remarkable shape of the expansion curve already described. The hardness was measured by the scleroscope invented by Shore (⁸). This method, when tested against other recognised ways of measuring hardness, has been found to give fairly concordant results for pure cast metals, as shown by Turner (⁸), but does not seem to be adapted to tests on non-metallic substances. However, its usefulness for comparative results on a series of alloys such as the present is unquestionable. The great advantage of the method consists in the rapidity with which a number of tests can be made, the specimens being merely pieces about one and a half inches long sawn off from the bars, and tested with the "blunt hammer" on the top surface after removing the rough skin due to casting by rubbing lightly on a fine file.

The results obtained are shown on the curve on Fig. 1 (p. 135). Up to the eutectic composition of 13 per cent. antimony, the hardness rises fairly uniformly. On passing this point hardness increases much more rapidly, and, passing through a maximum of 17.3 at about 80 per cent. antimony, it falls again very rapidly down to pure antimony. The sharp upward turn taken by the hardness curve at the eutectic composition corresponds with the maximum shown by the expansion curve at this point, and coincides with the first appearance of crystals of free antimony in the microstructure. Nothing noteworthy is to be found in the hardness curve at 50 per cent. antimony, where the expansion curve shows a second maximum.

Calvert and Johnson, by penetration tests, found that the alloy containing 23.5 per cent. antimony and 76.5 per cent. lead was four times as hard as pure lead. A reference to the curve will show that this ratio is confirmed by the scleroscope tests.

MICROSCOPIC EXAMINATION.

Although the microstructure of the antimony-lead alloys had been investigated by Stead (⁹) and Guillet (¹⁰), microsections of the bars cast for shrinkage curve observations were made nevertheless in the present research (see Figs. 1–10 in Plates IV.–VI.) in order to obtain information as to their internal composition and arrangement. For this purpose sections were sawn off about 2 inches from the end of each bar, where the extensometer pin entered it, and were polished in the usual way.

The greater part of the sections were examined without etching. By this treatment the hard white crystals of antimony were obtained standing out in a dark ground mass of eutectic.

In bars containing much antimony, this metal appears as primary white dendritic crystals. As the proportion of antimony decreases, the dendritic structure gradually disappears, and the antimony crystals assume the form of cubes, so well known in bearing metal structures. In two bars containing 14.6 per cent. and 23.2 per cent. antimony, these primary cubical crystals show a marked segregation to the top of the bar, leaving a perfectly homogeneous layer of eutectic at the bottom.

It would appear then that in casting alloys of this range of composition, which includes bearing metals and type metals, the casting temperature should be as low as possible if segregation is to be avoided. With higher percentages of antimony the dendritic structure effectually prevents segregation.

Bar VI. containing lead in excess of the eutectic composition shows polygonal lead crystals embedded in a matrix of dark eutectic, the banded structure of which is just visible between the white lead crystals at this magnification.

The specimen of pure lead shows the twinning of the crystals due to the effect of work during polishing. Most of the structures were coarse, the magnification for the series being only 100 diameters.

The fine structure of Bar IX. compared with those of its neighbours, Bar III. and Bar IV., has already been noted in connection with the expansion curve.

To sum up the foregoing results, it has been found that with this series of alloys, in contradistinction to the expansions of the copper-zinc alloys containing more than 40 per cent. copper, the amount of expansion on solidification is not proportional to the range of temperature over which solidification takes place. It has been suggested that the absence of solid solutions in the antimony-lead series of alloys may possibly account for this.

An unexpected maximum in the expansion curve at 50 per cent. antimony has been noted, and, on the evidence of the microsections, has been ascribed to some crystalline change.

The value for the melting point of the eutectic has been confirmed as 228° C., the figure obtained by Roland-Gosselin⁽⁶⁾ in his work on these alloys.

A maximum in the expansion curve was obtained at the eutectic composition, which point was also indicated on the hardness curve by a sharp upward turn.

The piping was noted in a few cases, and, judging from these, the amount of piping in the gate is largely governed by the casting temperature, the closer the latter approximates to the beginning of solidification, the greater will be the liability to pipe.

PRACTICAL CONSIDERATIONS.

Of the alloys containing 15–25 per cent. antimony, which include varieties of type metals and bearing metals, those with the lower percentage of antimony may be expected to give the sharpest castings, as the expansions for this range of composition gradually diminish from a maximum at 15 per cent. antimony to a minimum at about 30 per cent. The hardness, on the other hand, increases uniformly and fairly rapidly over this range, so that a cast alloy containing about 20 per cent. antimony would appear to combine a fairly high hardness figure with good casting properties.

PART II.—THE ALUMINIUM-ZINC ALLOYS.

Various reasons appeared to indicate the aluminium-zinc series as an interesting one to investigate in succession to the antimony-lead alloys.

More particularly, reference may be made to the increasing industrial importance of this series, and to the fact that the

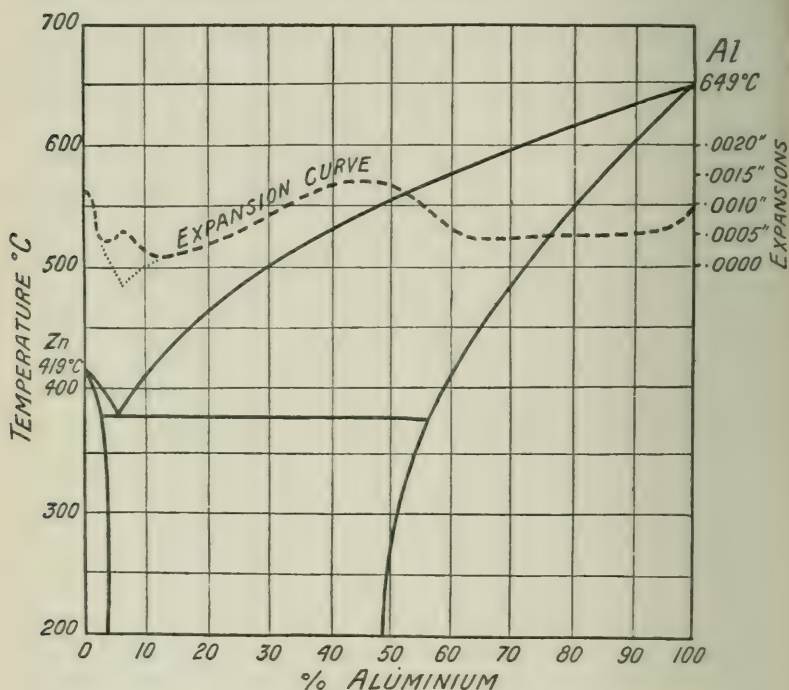


FIG. 2.—Equilibrium Diagram of Aluminium-zinc Alloys (Shepherd).

equilibrium diagram indicates the existence of mutual solubility of the two metals.

Shepherd (¹⁰) has conducted a microscopic and pyrometric research on these alloys, the results of which are included in his equilibrium diagram (Fig. 2). He did not obtain the solidus curve, however, and as this is not known at present, it is hoped that additional interest will attach to the present work.

The aluminium-zinc alloys had been partially investigated by F. D. Simpson, a former research scholar of this University, who carried out an unpublished series of tensile tests, and also took some curves with the dial extensometer already described. Only a few of his results are to hand, and he seems to have failed to observe any expansions with the alloys, with the single exception of that containing 90 per cent. aluminium. As the accuracy of these curves was doubtful, it was decided to test them by repeating one or two of the castings. Bars containing 5 per cent. and 35 per cent. aluminium were therefore cast, and an expansion was recorded in each case by means of the mirror extensometer, which will be described later. In consequence the aluminium-zinc series of alloys was adopted for investigation.

PREPARATION OF THE ALLOYS.

The alloys were made from pure aluminium supplied for the purpose by The British Aluminium Company of London, and found to contain on analysis the following impurities:—

	Per Cent.
Iron	0.16
Silicon	0.21

The zinc used was specially pure; it was obtained from Brunner, Mond & Co., of Northwich. According to analysis by Murray it contained—

	Per Cent.
Iron	0.01
Lead	0.006
Cadmium	0.05

with traces of arsenic and antimony.

Since both Shepherd ⁽¹⁰⁾ and Bancroft ⁽¹²⁾ lay great stress on the fact that aluminium readily absorbs silicon when melted in a fireclay crucible, some of the pure aluminium was melted in a salamander crucible, and heated to about 800° C. On testing the melt, the silicon content, which was then 0.25 per cent., showed very little increase on its original value (0.21 per cent.).

In making up the alloys, therefore, the aluminium was first melted in a salamander crucible set in a small injector furnace. The necessary amount of zinc was then added, when it was observed that in the case of the alloys containing much zinc the whole mass became solid. On further heating the substance melted, and the alloy was well stirred and poured. The melting up and alloying were effected under an atmosphere of coal gas to minimise oxidation.

APPARATUS USED.

Extensometer and cooling curve readings were taken simultaneously, as has been described in dealing with the antimony-lead alloys. The apparatus used was the same as that employed for the previous series, with the exception of

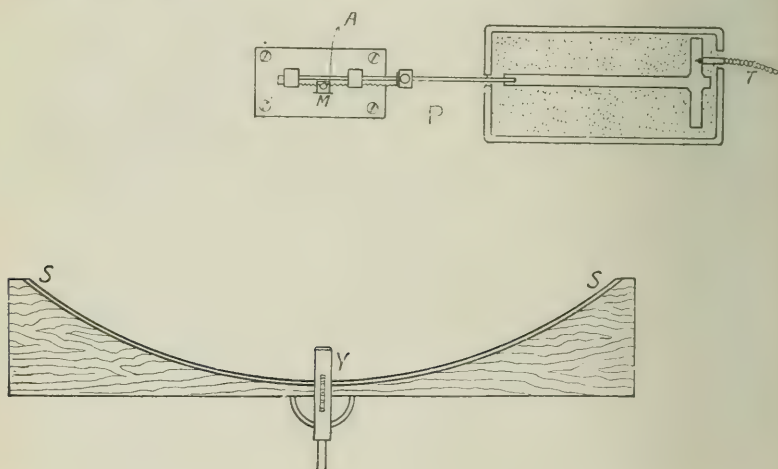


FIG. 3.—Plan of Mirror Extensometer.

the extensometer, which was an adaptation of an instrument made by Murray, and worked on the reflecting principle.

Referring to the plan (Fig. 3), the bottom box of the mould is shown made up just as for casting the antimony-lead alloys. The extensometer pin, P, was attached by a socket and thumb-screw to a rack which worked in two guides, and was capable of horizontal motion. This rack engaged with a pinion

fitted to a vertical spindle which worked easily between adjustable centres; on this spindle just above the pinion a mirror, M, was fixed, being a silvered microscopic cover glass. The rack and pinion were very carefully made, and as the position of the spindle was adjustable, it was a simple matter to arrange the apparatus so that there was no play between the moving parts.

Changes in length of the test bar in the mould were thus communicated to the mirror, which turned through an angle proportional to the length variation of the test. A boxwood metre scale, SS, was bent to the shape of an arc of radius equal to its distance from the mirror, and mounted on a stand;

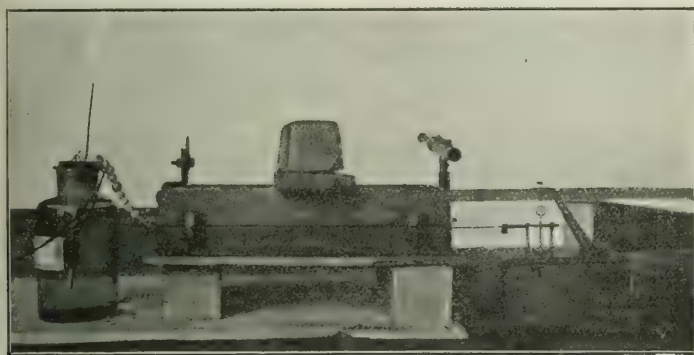


FIG. 4.—Mirror Extensometer.

immediately above this scale was a cross-wired telescope, Y, by which the reflections of the scale in the mirror were observed, and thus values were obtained from which the shrinkage curves were plotted.

The magnification adopted was about 1 : 400. As compared with the older dial form, this extensometer gives increased magnification and sensitiveness owing to the use of a larger scale, and a more accurate method of reading, it being quite easy to read rapidly to 0.5 millimetre. By this means any critical part of the curve may be established by a much greater number of points than was possible when using the dial extensometer. The question of play between the moving parts, and of possible strain in the case of very large length

alterations are also eliminated in this apparatus. The photograph (Fig. 4) shows the apparatus set up ready for casting; an ingot of lead is placed on the top of the mould to ensure good contact between the top and bottom boxes. The method of casting the bars was exactly the same as when working with the antimony-lead alloys. As it appeared possible that the expansion of the pin connecting the test bar with the extensometer might introduce an appreciable error, a check casting was made of one of the bars, but a thin glass rod was employed in place of the iron wire ordinarily used as a pin. Within the range of experimental error the results in each case were identical. The use of "invar," which had been originally contemplated, was therefore abandoned.

ASSAY OF THE BARS.

The assay of aluminium-zinc alloys described by Seligman and Willot⁽¹¹⁾, comprising solution of the sample in a strong solution of caustic soda, followed by precipitation of the zinc with sulphuretted hydrogen, redissolving the zinc sulphide in hydrochloric acid, and titrating, gave good results for alloys containing high percentages of aluminium. But for alloys containing much zinc this method was impracticable, as the samples were only partly soluble in the caustic soda solution. High zinc alloys were simply dissolved in hydrochloric acid and titrated with potassium ferrocyanide without any previous separation. Bars containing less than 75 per cent. aluminium were assayed by this direct process. The method was calibrated by introducing varying amounts of aluminium into the solution when standardising the potassium ferrocyanide solution, and a curve was drawn expressing the effect of aluminium on the assay results. By this means a rapid and accurate method of analysis was obtained. Bars containing upwards of 75 per cent. of aluminium were subjected to precipitation with sulphuretted hydrogen, as described by Seligman and Willot, before titrating. The aluminium was obtained by difference in every case.

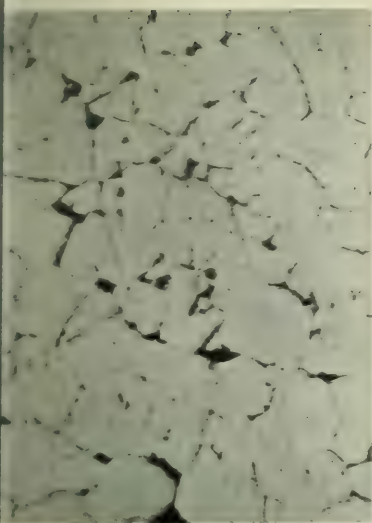


FIG. 2. Bar XI. 87.7 per cent. Antimony.
Magnified 100 diameters.

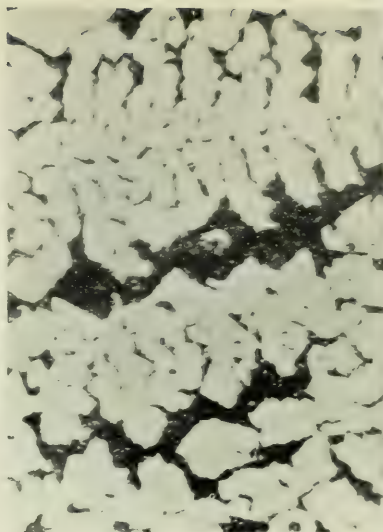


FIG. 4. Bar III. 57.1 per cent. Antimony.
Magnified 100 diameters.

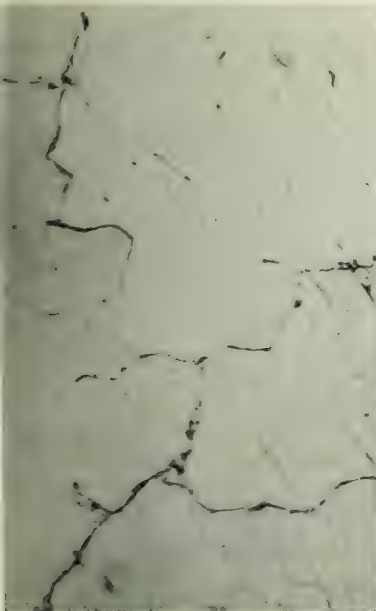


FIG. 1.—Bar I. Pure Antimony. Magnified 100 diameters.

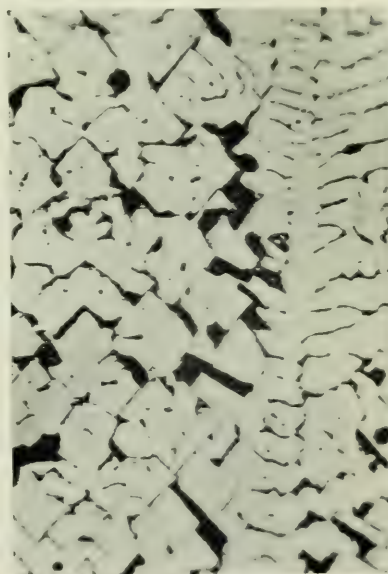


FIG. 3.—Bar II. 77.5 per cent. Antimony.
Magnified 100 diameters.



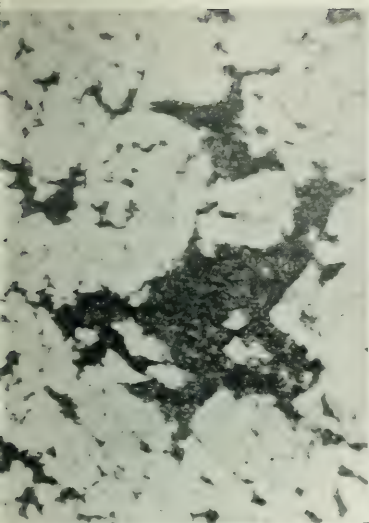


FIG. 6.—Bar IV. 37.2 per cent. Antimony.
Magnified 100 diameters.

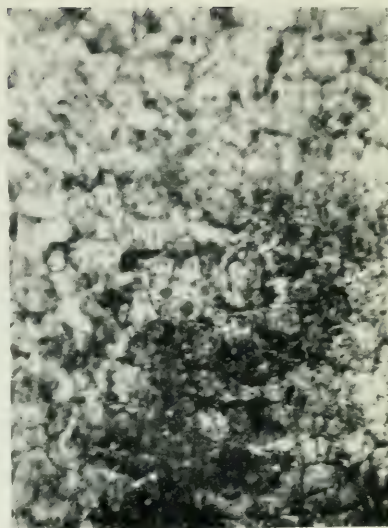


FIG. 8.—Bar VI. 5.1 per cent. Antimony.
Magnified 100 diameters.

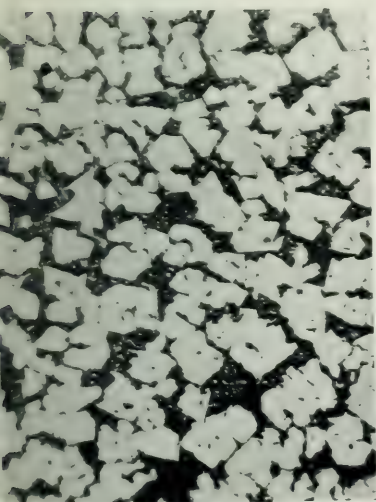


FIG. 5.—Bar IX. 48.8 per cent. Antimony.
Magnified 100 diameters.

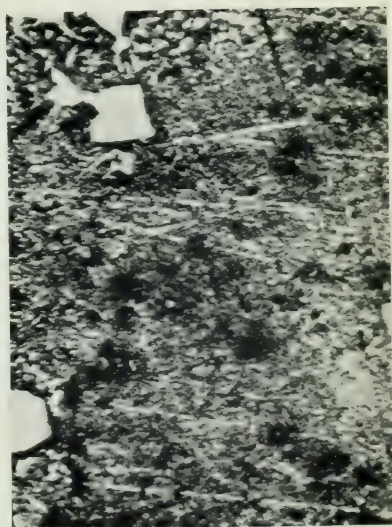


FIG. 7.—Bar V. 14.6 per cent. Antimony.
Magnified 100 diameters.

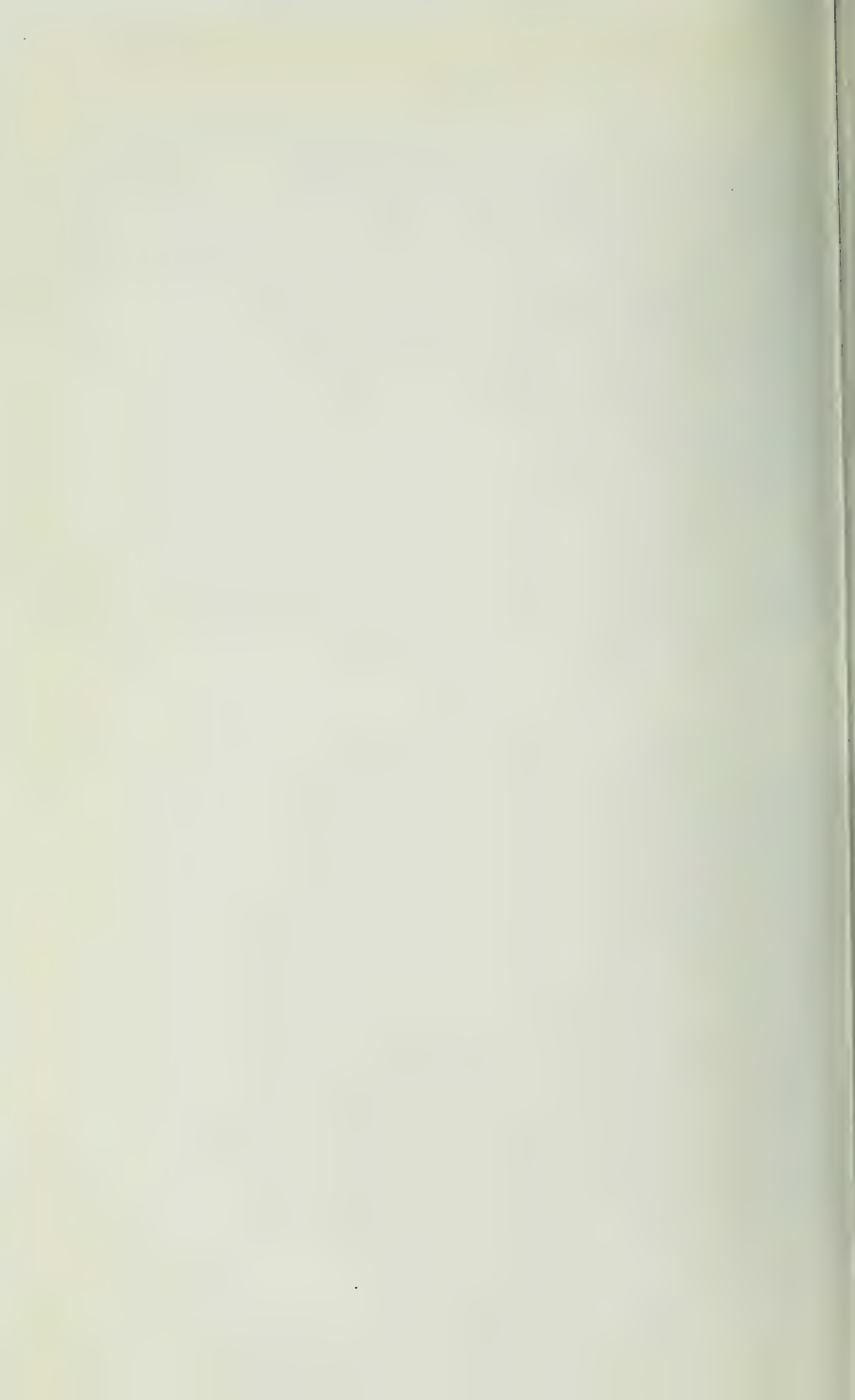


PLATE VI

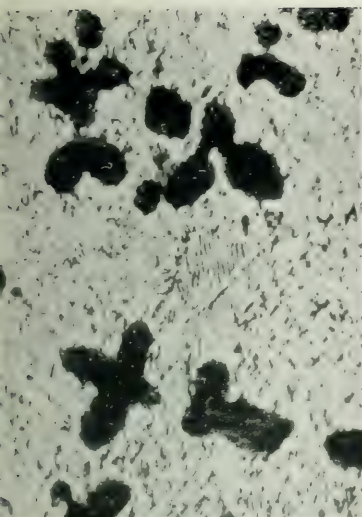


FIG. 10. Antimony-Lead Eutectic (Hague).

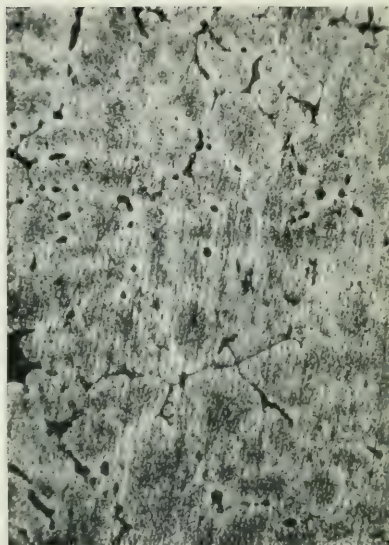


FIG. 12. — Bar XI. 79.28 per cent. Aluminum.
Magnified 100 diameters.



FIG. 9. — Bar VII. Pure Lead.
Magnified 100 diameters.



FIG. 11. — Bar XII. 89.33 per cent. Aluminum.
Magnified 100 diameters.



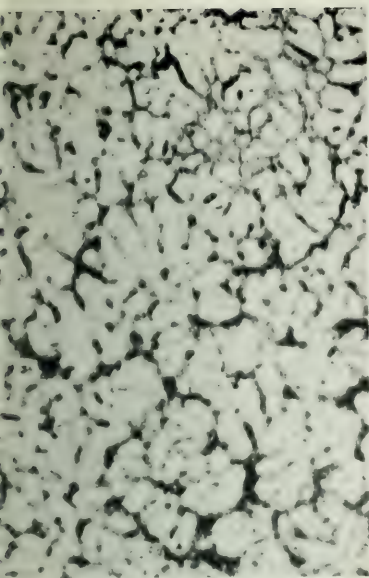


FIG. 14.—Bar VIII. 49.84 per cent. Aluminium.
Magnified 100 diameters.

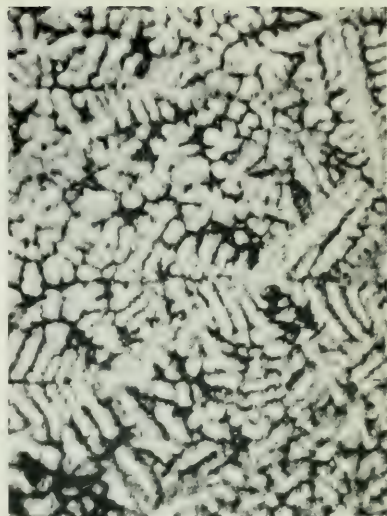


FIG. 16.—Bar V. 21.03 per cent. Aluminium.
Magnified 100 diameters.

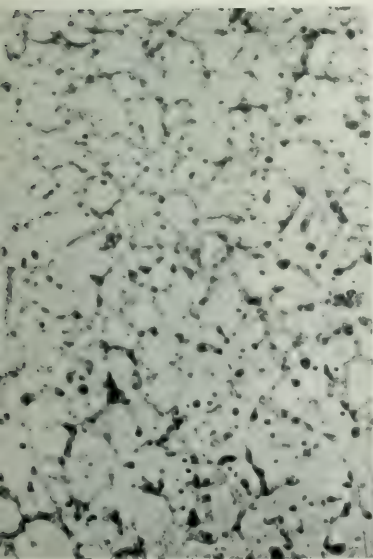


FIG. 13.—Bar IX. 60.21 per cent. Aluminium.
Magnified 100 diameters.

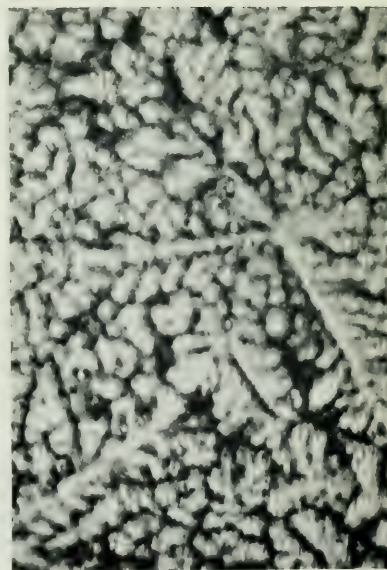


FIG. 15.—Bar VI. 30.55 per cent. Aluminium.
Magnified 100 diameters.



FIG. 17. —Bar IV. 9.48 per cent. Aluminium.
Magnified 100 diameters.

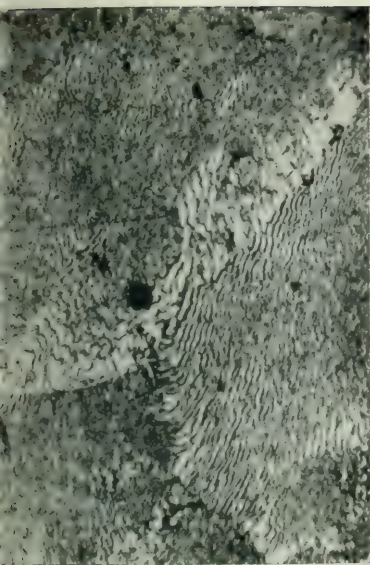


FIG. 18. —Bar III. 4.31 per cent. Aluminium.
Magnified 200 diameters.



FIG. 19. —Bar III. 4.31 per cent. Aluminium.
Magnified 100 diameters.

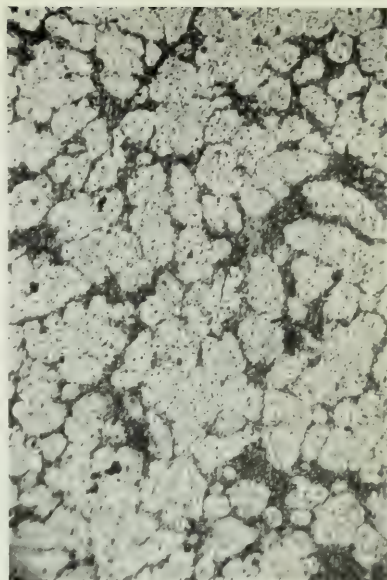
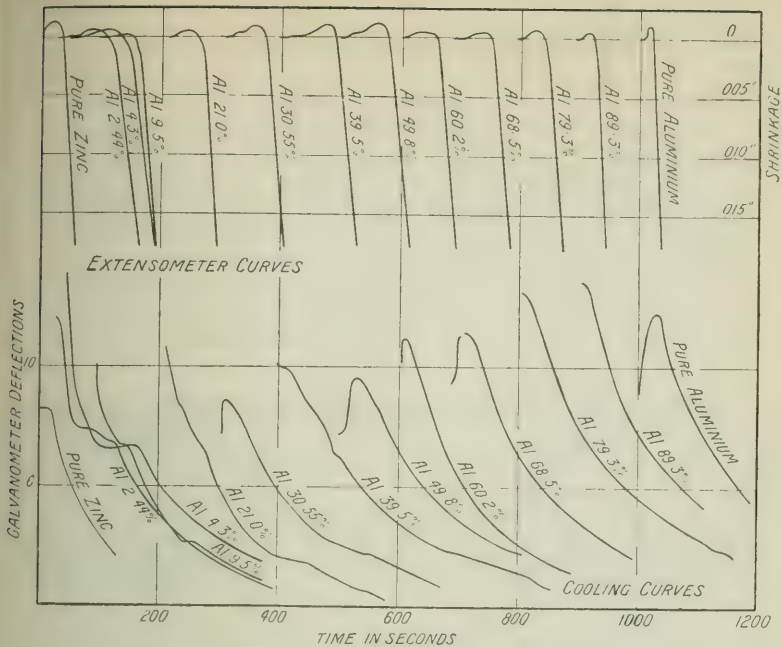
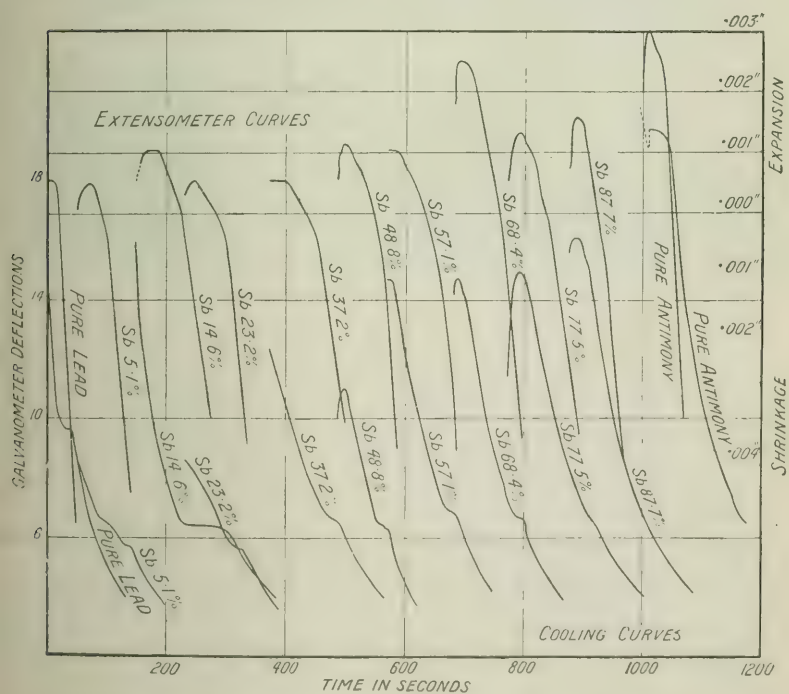


FIG. 20. —Bar II. 2.4 per cent. Aluminium.
Magnified 100 diameters.



Cooling and Shrinkage Curves of Aluminium-zinc Alloys.



Cooling and Shrinkage Curves of Antimony-lead Alloys.

DESCRIPTION OF THE BARS.

All the alloys gave good castings, but those containing 50 to 60 per cent. aluminium gave the cleanest and sharpest castings of the series.

It was thought that the amount of piping in the gates of the cast bars might be of some value in subsequently considering the expansion curves, and the character of the gate

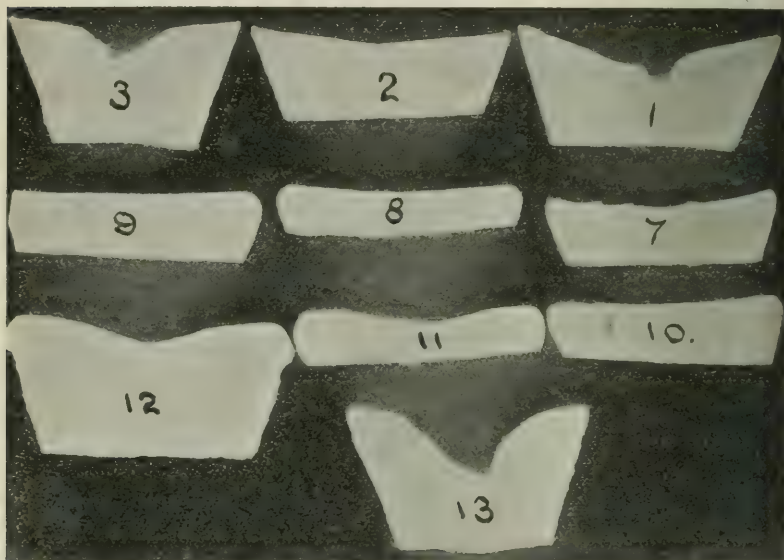


FIG. 6.—Piping of Aluminium-zinc Alloys.

of each bar was noted. As will be seen from the photograph (Fig. 6), the greatest amount of piping is shown by Bar I. (pure zinc), Bar III. (4.31 per cent. aluminium, the eutectic alloy), and Bar XIII. (pure aluminium). With the antimony-lead alloys it was noticed that the nearer the casting temperature was to the beginning of solidification, the greater was the piping. This is not true of the present series of alloys, for Bars VII., VIII., IX., and X., all of which were poured at a very low temperature, exhibit little or no piping in their gates. Bars IV., V., and VI. show no piping at all.

Arguing from these results, it would appear that substances which solidify at a more or less constant temperature (such as pure metals and eutectics) show the greatest tendency to pipe, although the amount of piping is governed also by the casting temperature. The numerical results obtained in this part of the research are included in Table II.

TABLE II.

Bar.	Aluminium.	Zinc.	Expansion (in inches) on 12 Inches.	Hardness.	Remarks.
	Per Cent.	Per Cent.			
I. . .	...	100.0	.00126	14.0	Much piped.
II. . .	2.44	97.56	.00058	22.0	Slightly piped.
III. . .	4.31	95.69	.00063	24.5	Eutectic alloy; much piped.
IV. . .	9.48	90.52	.00029	28.0	Not piped.
V. . .	21.03	78.97	.00048	42.9	" "
VI. . .	30.55	69.45	.00084	38.5	Not piped; clean casting. Drilled much softer than V.
VII. . .	39.54	60.46	.00116	43.3	Not piped; seemed harder than V. when drilling.
VIII. . .	49.84	50.16	.00126	51.8	Not piped; excellent casting.
IX. . .	60.21	39.79	.00048	41.2	Not piped; very sharp casting.
X. . .	68.54	31.46	.00056	35.0	Not piped; much softer than Bars VII. and VIII. when drilling.
XI. . .	79.28	20.72	.00066	25.8	Slightly piped.
XII. . .	89.33	10.67	.00058	7.8	Distinctly piped.
XIII. . .	100.0	...	.00106	2.8	Much piped.

As was the case with the antimony-lead alloys, the highest temperature recorded by the thermo-couple placed in the mould (the "casting temperature") was in many cases below that of the commencement of solidification, as deduced from Shepherd's diagram.

This is unfortunate, as it detracts from the value of the cooling curves, but it was unavoidable on account of the rapidity of cooling, and the necessity of pouring at a low temperature in order to obtain reliable readings for the shrink-

age curves, which are of primary importance. There is reason to believe that in some cases distinct surfusion occurred, and possibly also the "lag" of the pyrometer prevented its reaching the maximum temperature of the cast. It has, however, been thought best to present the curves in their entirety. All the alloys were perfectly fluid when cast.

SHRINKAGE OF THE ALUMINIUM-ZINC ALLOYS.

Shepherd⁽¹⁰⁾ and Bancroft⁽¹²⁾ attribute the superior casting properties of these alloys to the increase of fluidity and decrease of surface tension obtained on alloying, and express their doubts as to the influence of possible expansion on solidification in this respect.

That fluidity and low surface tension are of importance in determining the good casting properties of these alloys is shown by the nature of the tops of the gates which have perfectly rounded edges for all alloys containing from 50 to 90 per cent. aluminium. But whilst these factors undoubtedly affect the casting properties of any material, it may be argued fairly in this case that the excellent castings obtained were due in part to expansion on freezing, the best castings being obtained with alloys containing from 40 to 60 per cent. aluminium, a range of composition which includes the maximum expansion of the series.

The shrinkage curves obtained with the pure metals confirm Murray's results, both aluminium and zinc bars showing considerable expansion on solidification. The whole series of shrinkage and cooling curves of these alloys is shown on Fig. 5, the shrinkage curves being shown in the upper half of the diagram and the cooling curves below them. For the sake of clearness, only the earlier parts of the shrinkage curves are shown, contraction being perfectly uniform after the first eight or ten readings.

The curve of maximum expansion for each alloy (see Fig. 2) shows that the expansion on solidification drops from that of pure zinc to a minimum at 2.4 per cent. aluminium, exhibits a small maximum at the eutectic composition (4.31 per cent. aluminium), and then rises uniformly to a second much larger

maximum at about 50 per cent. aluminium, after which it undergoes a sudden fall, and finally rises, slowly at first and then more rapidly, to the large expansion shown by pure aluminium.

This curve exhibits some interesting points when compared with the equilibrium diagram, and has therefore been added to the latter (Fig. 2). The maximum shown at the eutectic point is worthy of notice, when it is remembered that a similar maximum was obtained at the eutectic composition of the antimony-lead alloys. But if one disregards this maximum for the moment as being a characteristic property of eutectics, which, indeed, seems a fairly justifiable supposition, the expansion curve might be continued underneath the eutectic maximum, as shown on the equilibrium diagram, and would then follow the shape of the liquidus very closely from nearly pure zinc up to about 50 per cent. aluminium.

The expansions of the alloys within these limits (2 to 45 per cent. aluminium) are therefore proportional to the distance of the solidus from the liquidus (since the solidus over this range is the horizontal eutectic line), and may be said to support Murray's suggestion, that expansion is proportional to range of temperature during solidification. With the disappearance of the eutectic, however, on exceeding 50 per cent. aluminium, the expansion suddenly falls, and the alloys, now consisting of a simple solid solution of zinc in aluminium of varying degrees of concentration, show a more or less uniform expansion until, with more than 90 per cent. aluminium, the larger expansion of this metal begins to make its influence felt, and the curve rises sharply.

HARDNESS.

Following the same method of procedure as in dealing with the antimony-lead alloys, the hardness of the aluminium-zinc test bars was investigated, again using the scleroscope.

The curve obtained was very much what might be expected (see Fig. 7); the only outstanding feature is a small minimum at about 30 per cent. aluminium. This was confirmed on

machining two sides of the test pieces perfectly parallel and again testing their hardness.

The hardness increases rapidly from pure zinc up to the eutectic composition, and then more slowly up to a small maximum at about 20* per cent. aluminium, whence it falls to a minimum at 30 per cent., and rises again to 50 per cent. aluminium, the hardest alloy of the series. This point corresponds with the solid solution of zinc in aluminium containing the largest possible amount of zinc compatible with a homogeneous structure. After passing this point the hardness falls

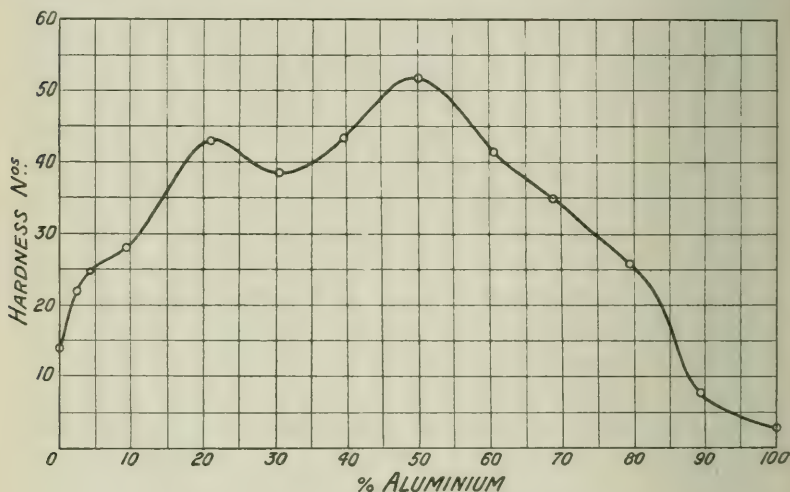


FIG. 7.—Hardness of Aluminium-zinc Alloys.

uniformly to pure aluminium. A rough gauge of the hardness of the bars was obtained when drilling out the samples for analysis before the hardness tests were made, and it confirmed the general shape of the curve and the minimum at 30 per cent. aluminium subsequently found by scleroscopic tests.

The bars were all fractured in a vice by tapping with a hammer. The influence of small amounts of aluminium on zinc was very noticeable. Bar I. (pure zinc) showed the usual coarsely crystalline structure. Bar II., containing 2.4 per cent.

* It may be observed that the arrest at 250° C., which will be referred to later, shows its maximum effect at about this composition.

aluminium, had a fine grained fracture, and stood a great deal more hammering than Bar I. before it broke. The eutectic alloy (4·31 per cent. aluminium) showed a fracture much coarser than that of Bar II., whilst Bar V. (21 per cent.) showed a very fine fracture, somewhat resembling that of tool steel, and was very difficult indeed to break. Most of the bars snapped without appreciably bending, a small amount of ductility being observed only when the eutectic limit of 50 per cent. aluminium had been well passed.

TENSILE TESTS.

A series of values for the tenacity of the aluminium-zinc alloys was obtained by Simpson, and the results have been

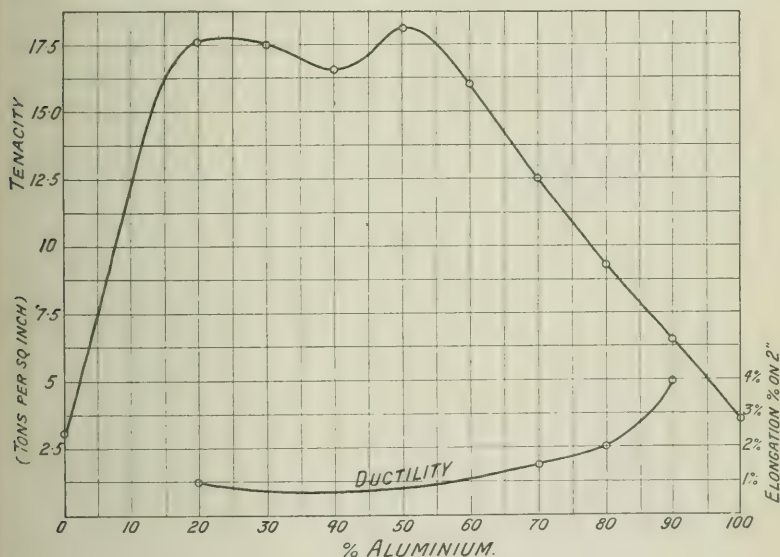


FIG. 8.—Tenacity of Aluminium-zinc Alloys (after Simpson).

plotted, giving the curve on Fig. 8, which rises rapidly on adding aluminium to zinc up to 20 per cent., when it reaches its maximum value of 18 tons. This figure is maintained until 45 per cent. aluminium is passed, when it drops uniformly to pure aluminium, with a tensile strength of about 3·6 tons.

The maximum tensile strength of the series is thus covered

by alloys which consist of a saturated solid solution of zinc in aluminium with varying amounts of eutectic, and appears to reach its highest value when the amount of eutectic present is vanishingly small. Microscopic examination of the alloys included in this range of composition shows the structure to be essentially dendritic. The curve, which gives the values of the tenacity after annealing for three hours at 300° C., is in fair agreement with that obtained by W. D. Bancroft (¹²), who conducted his tensile tests on cast alloys, so that simple heat treatment without work has little effect on the tenacity, but it is said to improve the ductility considerably.

From the equilibrium diagram it will be seen that the industrial alloys, when in perfect equilibrium, consist of a homogeneous solution of zinc in aluminium. In the cast state, however, small amounts of eutectic are always present in these alloys when rich in zinc, so that heat treatment and work would be expected to have a beneficial effect, tending to increase uniformity of structure. This has been realised in the case of the alloy containing 88.7 per cent. aluminium, and the improvement in the mechanical properties is very evident (¹³). (See Table IV.)

TABLE III.

	Chill Cast.	Drop Forged.
Yield Point . . .	5.3 tons	11.0 tons
Tenacity . . .	7.5 tons	14.0 tons
Elongation . . .	3.0 per cent.	12.4 per cent.

Industrial applications of the aluminium-zinc alloys are limited by the fact that they become brittle under the influence of repeated shock.

MICROSCOPIC EXAMINATION.

Specimens for microscopic examination were taken from each bar. The softness of the alloys at either end of the series was again the cause of some difficulty in polishing. Alloys containing up to 50 per cent. aluminium were etched with dilute nitric acid; with higher percentages of aluminium, potash solution was found to give better results as an etching agent.

As cooling was comparatively rapid, perfect equilibrium was not obtained in many of the bars, and the eutectic appears in several specimens which, on annealing, would give a uniform one-constituent structure.

The magnification for the series was 100 diameters. Microphotographs of the pure metals were not taken. Referring to Figs. 11 to 20, in the series of microphotographs. Bar II. (2.44 per cent. aluminium) shows primary granular crystals of a solution of aluminium in zinc in a matrix of dark eutectic; the banded structure of the latter, being very coarse, is just visible between some of the white crystals at this magnification. Bar III. (4.31 per cent. aluminium) appears to be composed entirely of eutectic, the typical banded structure being well developed. This is also shown magnified 200 diameters. Bars IV., V., VI., VII. (9.5 to 39.5 per cent. aluminium) show primary white crystals, consisting of a saturated solution of zinc in aluminium, embedded in a matrix of eutectic. The primary crystals gradually assume a more and more dendritic structure as the percentage of aluminium increases. Small quantities of a blue-grey constituent, often in minute cubical crystals, were first noticed in Bar V., and persist in varying amounts up to Bar X. (68.5 per cent. aluminium). On exceeding 45 per cent. aluminium the alloy is no longer a saturated solid solution of zinc in aluminium, and the eutectic disappears. This accounts for the difference in structure between Bar VI. (30.6 per cent.), which is markedly dendritic, and Bar VIII. (49.8 per cent. aluminium); the latter consists of solid solution of zinc in aluminium, with small amounts of eutectic, which would have disappeared entirely had the alloy been slowly cooled or annealed. Bar IX. (60.2 per cent. aluminium) closely resembles Bar VIII., and on repeated hammering and annealing its structure was found to become perfectly homogeneous, this being the characteristic appearance of the other bars up to 89.3 per cent. aluminium.

PYROMETRIC RESULTS.

Although the cooling curves obtained from the shrinkage tests of this series of alloys were unsatisfactory at the higher

temperatures, on account of the rapid cooling and the necessity of casting at a low temperature, an interesting feature was yet exhibited by some of the curves.

This was an inversion, taking place between 200° and 300° C., which was found in the cooling curves of bars containing about 10 to 40 per cent. of aluminium.

In order to further investigate this halt, slow cooling curves of Bars II. to IX. (2.44 to 60.21 per cent. of aluminium) were taken by means of a delicate potentiometer, galvanometer, and thermo-couple.

A faint indication of the halt was found at 2.44 per cent. of aluminium at a temperature of 255° C.

As the percentage of aluminium increased the effect of the halt became more and more apparent, until it reached its maximum at about 17 per cent. of aluminium and 83 per cent. of zinc, a proportion which approximates closely to the formula AlZn_2 .

As the aluminium content is still further increased the duration of the halt becomes less and less, and finally it disappears altogether between 50 and 60 per cent. of aluminium. These facts are shown on the equilibrium diagram (Fig. 9), which is drawn from the data obtained in this part of the research, with the exception of the curves of solid solubility.

A series of quenching and annealing experiments have been carried out on an alloy containing 17 per cent. of aluminium, but sufficient time to arrive at the explanation of this halt has not yet been available.

It may be remarked, however, that the specimen quenched from 330° C. did not show eutectic structure, although well within the eutectic limits, whilst the annealed alloy, which was slowly cooled through the critical range of the halt (280° to 220° C.), showed a well-defined pearlitic structure in the matrix between the primary crystals.

The eutectic halt was found at 380° C., in agreement with the figure obtained by Shepherd.

On recording the results so far obtained with this series of alloys, the most noticeable feature is that the alloy containing 49.8 per cent. of aluminium, corresponding to the disappear-

ance of eutectic and attainment of a homogeneous structure, shows the maximum hardness, tenacity, and expansion on solidification of the series. Its ductility, however, is too low for practical purposes, the elongation of the annealed alloy being well under 1 per cent. on 2 inches.

The piping of these alloys was noted. It was practically restricted to the pure metals and the eutectic alloy, and appears to be chiefly influenced by the range of temperature

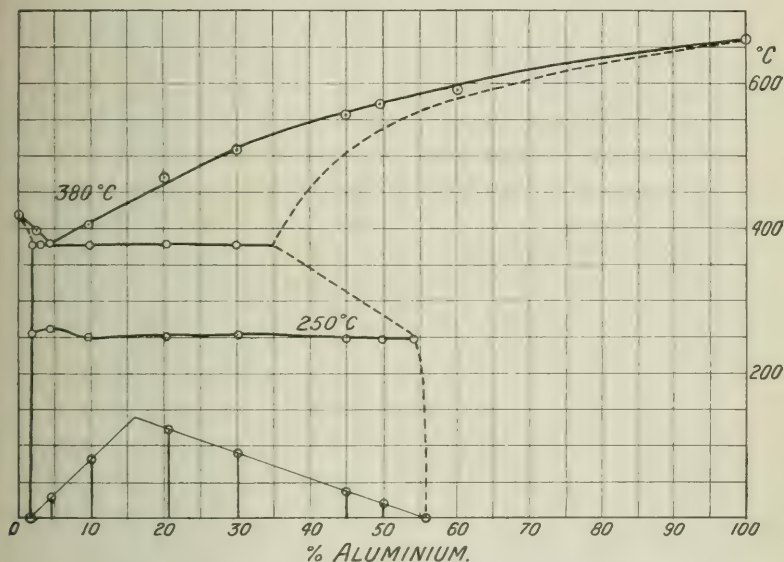


FIG. 9.—Equilibrium Diagram of the Aluminium-zinc Alloys.

during solidification; the results obtained in this respect dispute the generally accepted idea that piping is an evidence of contraction.

The curve expressing the maximum expansions of the cast bars shows two maxima, a small one at the eutectic point, and a much larger one at about 50 per cent. If the eutectic expansion be disregarded as being a constitutional property of eutectics, the expansions on solidification are approximately proportional to the range of temperature over which solidification takes place for alloys containing from 2 to 50 per cent. aluminium. The direction of the solidus on exceeding 50 per

cent. aluminium is not yet known. but has been drawn in Shepherd's equilibrium diagram in the direction which it would be expected to take. From considerations of the expansions of the bars of aluminium-rich alloys, however, it should be drawn very much more curved. and would appear as shown dotted in Fig. 9. Further work on this subject is necessary before it can be definitely stated which of these two lines most closely follows the path of the actual solidus. A halt at 250° C. has been noticed in the cooling curves of alloys containing 2 to 50 per cent. aluminium. This indicates some structural change at the temperature shown by the horizontal line in the equilibrium diagram (Fig. 9), but the exact nature of the transformation has not yet been fully investigated.

On rehearsing the results obtained in the shrinkage curves of cast bars of the antimony-lead and aluminium-zinc alloys, it is obvious that the relation between expansion and range of temperature during solidification is much more complicated than was suggested by Murray; and one general theory which shall apply to all alloys cannot yet be deduced.

The efficacy of the extensometer used for measuring volume changes has been questioned, on the supposition that it does not measure changes in volume, but only changes in length. For absolute measurements of contraction this may be true, but in dealing with a series of alloys it is an instrument of no little value, and gives comparative results which are of undoubted help in indicating structural changes coincident with fall of temperature. From the technical standpoint, the usefulness of the extensometer lies in the fact that it gives a simple way of obtaining practical results for the shrinkage of materials cast under working conditions.

A glance at the diagrams showing the shrinkage and cooling curves of the various alloys will make it clear that the expansions in the two series examined all take place *during solidification*, no arrest in the shrinkage curves being noticed after the eutectic halt in the cooling curve (signifying complete solidification) is passed. In iron alloys, on the other hand, expansions are met with which occur after the metal has long passed the eutectic point.

The changes in length of the bars are observed from the very beginning of solidification, when it is probable that a network of crystals of the less fusible constituents forms in the mould and sets round the end of the extensometer pin. These crystals serve as a sponge, and hold up the still liquid portion of the alloy scattered throughout the bar.

The heat changes due to the freezing of the more fusible constituents produce corresponding volume changes in the already solid sponge, and the record of these changes is presented in the shrinkage curve.

The amount of liquid material left in the interstices of the crystalline network when sufficient has solidified to establish a connection with the extensometer pin is roughly proportional to the distance of the solidus from the liquidus, but supercooling, latent heat of solidification, freezing point, specific heat and coefficient of expansion of the material, all claim some consideration when the ultimate expansion or contraction during solidification is in question. Allotropic changes and crystal growth will also have an influence of some kind on the volume changes when a material freezes.

SHRINKAGE OF THE COPPER-TIN ALLOYS.

Three preliminary casts of these alloys were made, using the mirror extensometer described in dealing with the aluminium-zinc alloys.

Although the results are meagre, they appear to confirm the direct proportion existing between expansion and range of temperature during solidification, and are therefore included here.

With 89 per cent. copper and 11 per cent. tin, an enormous expansion during freezing was obtained, whilst a single solid solution (pure α) separated out; the distance of the solidus from the liquidus on the equilibrium diagram is here at its maximum. In the case of a bell metal bar, containing 78 per cent. copper and 22 per cent. tin, a much smaller expansion was obtained; pure α is still separating out, but the distance between the solidus and the liquidus is much smaller than for the 89 per cent. alloy.

The last bar cast contained 66 per cent. copper and 34 per cent. tin, and showed a very large expansion, which may perhaps indicate the existence of the doubtful compound Cu_4Sn . This series should prove of great practical interest, and it is clear from the above trials that it would certainly repay investigation by means of the extensometer.

In conclusion, the writer wishes to express his great appreciation of the kindly interest and counsel of Professor Turner. Great indebtedness is felt to Mr. O. F. Hudson, whose help and advice, more especially in the pyrometric and microscopic work, have been invaluable. The funds necessary for the research have been supplied from the foundation of the late T. Aubrey Bowen.

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DISCUSSION.

Mr. D. EWEN, after the paper on "Shrinkage of the Antimony-Lead Alloys, and of the Aluminium-Zinc Alloys during and after Solidification," jointly prepared by himself and Professor T. Turner, M.Sc., had been read in abstract by Professor Turner, said he was very grateful to be relieved of the responsibility of introducing the paper. Personally, he was inclined to think that by far the most interesting fact in the paper was the halt at 250° C. in the cooling curve of the aluminium-zinc alloys. It only extended over a limited range from 2 per cent. of aluminium up to about 55 per cent. It therefore covered the range of composition in which the eutectic was present. He thought that this subject required a great deal more investigation before they could decide what caused that halt. Personally, he did not think that it was a question of crystalline change of any sort. He had carried out a few preliminary investigations, which seemed to show that when alloys were quenched above the temperature of those halts they showed no eutectic structure, even though they might be at the eutectic composition of 5 per cent. aluminium. When quenched below the halt they showed quite a coarse eutectic structure.

Mr. F. JOHNSON, M.Sc. (Birmingham), said he had very little to say in the discussion of the paper, but he would like to put two points to the authors. First, in casting the bars, did they find any difficulty in obtaining sound castings? He should imagine that difficulty would be more likely to be experienced with brass or bronze, but possibly it was experienced also in these cases. The conditions of the experiment, which necessitated complete freedom of movement in a longitudinal direction, precluded the possibility of arranging for a "riser," this involving entire reliance upon the porosity of the moulds, to allow of the escape of dissolved gases, displaced air, or steam from imperfectly dried moulds. Disregarding the latter, which the authors took full precautions to guard against, it would seem quite possible that bubbles of entrapped air escaping during solidification might easily introduce an influential effect upon the movement of the extensometer pin. Then as regards the gases, the tendency for molten alloys to dissolve gases in proportions which vary according to their composition, conditions of melting, and temperature, and to reject them during solidification, might in some instances, particularly in the case of copper alloys, be the cause of violent mechanical disturbances which would, in a great measure, mask the actual physical changes which took place. On page 142 the authors mentioned that in the case of aluminium-zinc alloys containing much zinc, it was noticed that the addition of the zinc caused the whole mass to solidify. Would not that be due to the lowering of the temperature due to the coldness of the solid zinc?

Professor H. C. H. CARPENTER, M.A., Vice-President, said that he had had the pleasure of reading that paper under somewhat different

circumstances a few months ago, and he had formed a favourable opinion of the careful way in which the work had been carried out. He would like to offer his congratulations to Professor Turner and Mr. Ewen thereon. There was a point in the introduction to which he would like to refer, and in particular he would like to have the question settled as to whether the apparent volume increase was a real one. It was quite true, as Professor Turner said, that practically it was of no great importance, but scientifically it was of importance. Those of them who were primarily scientific desired to know exactly what it was that was being measured. It would be quite possible to settle the matter without any great difficulty, and they would be very grateful if Professor Turner would settle that point.

Of the two series of alloys, the more interesting was the zinc-aluminium; but there was just one point he would like to mention with regard to the antimony-lead series. The authors appeared to be in disagreement with Wüst as regards the question whether antimony solidified with expansion or not. They found a very decided expansion, whereas Wüst found none.

Professor TURNER remarked that as far as he interpreted Wüst's results he found no expansion, but he (Professor Turner) and Mr. Ewen found expansion over and over again, and so had many people. There was not the slightest doubt in the world about it.

Professor CARPENTER, continuing, said that the purity of the authors' antimony was 99.5 per cent., so that there was half per cent. of something else. He would suggest that the possible discrepancy lay purely in regard to the composition. Probably Professor Wüst and Professor Turner worked with different materials, and there might, therefore, be no real discrepancy. Possibly, if the antimony were pure, there would be no difference.

Then an interesting point in the other series of alloys related to the new inversion. Here was another inversion which had previously escaped notice. He was sorry Dr. Rosenhain was not there, for the latter had told him that he had found the same inversion a few months ago. Thus the discovery had been made independently by both investigators, and they might take it, therefore, to be fully established. He hoped that Mr. Ewen would continue the work and tell them what was the structural meaning of that inversion. He gathered that experiments were proceeding on that point, and he hoped they would give the necessary information. Also, if possible, he would like to have the solidus curve of the aluminium series further dealt with. Much experimental work on that side was still wanted.

Dr. DESCH (Glasgow) said he would not have intervened in the discussion but for the fact that reference had been made in the paper to a criticism of the general method adopted. That criticism was first put forward by himself in the discussion at the Manchester meeting, and

was afterwards supported by Mr. Edwards of Manchester and by Dr. Rosenhain. The objection he took was that he could not regard the increase in length observed as being due to expansion of the metal. He agreed that the volume would vary in proportion to the length after the bar was once solidified, but during the process of solidification they were not dealing with a constant quantity of metal. The experiments undoubtedly showed that during the process of cooling the bar increased in length, and he attributed the increase to the thrust exerted by the crystallites in the direction of their growth. The existence of such a thrust was an ascertained fact, although the experiments had not been made with metals but with non-metallic substances. They could not say that there had been an actual expansion of the metal, unless the quantity dealt with was quite constant. As the outer shell increased in length its contents were made up by metal taken from the gate. In accordance with this view, the gates in the casting of the copper-zinc alloys showed piping. Had there been a real expansion there would have been a rise of metal in the gate. For that reason, it did not seem to him that the experiments gave any definite evidence of the volume changes taking place during the process of solidification. From the point of view of the practical man probably that did not matter. The very careful experiments described in the paper undoubtedly did show the changes of dimensions during casting as compared with the dimensions of the pattern. That was a matter of interest to brassfounders. From the physico-chemical standpoint, however, there were serious difficulties in the way of accepting the view that any expansion took place during the solidification of alloys of this kind. They required direct evidence based on measurements of the volume of a definite quantity of metal, in order that trustworthy conclusions could be obtained. He fully recognised the great practical value of the investigation, but he must ask Professor Turner to excuse him if he continued to retain for the present his sceptical attitude as to the physico-chemical interpretation of the results.

The CHAIRMAN said he would ask any other gentleman proposing to join in the discussion to send any remarks to the Secretary in writing for inclusion in the *Journal*.

Mr. DONALD EWEN, replying, said that with regard to the condition of the cast bars, all the castings were perfectly sound and free from blowholes. Both the series of alloys were cast at very low temperatures, so that steam would not enter largely into the casting process, nor would water vapour get into the metal. There seemed no reason to suppose, and he should personally hardly think it probable, that gaseous pressure would have any effect on the expansion results as shown by the extensometer. With regard to Dr. Desch's remarks, he (the speaker) must certainly agree with Professor Turner about the genuineness of the expansion, because with the aluminium-zinc alloys the maximum expansion was shown at about 50 per cent., which applied to Bar VIII.

(See Table II. on page 147.) A reference to Fig. 6 on page 146 shows that Bar VIII. showed no piping whatever. On the other hand, Bar I., which showed the same amount of expansion as Bar VIII., had a gate which was considerably piped. It would therefore appear that the piping has no connection with the expansion of the bar.

Professor TURNER, also replying, said that proof of the correctness of the principle was furnished by experiments with cast iron. In the case of cast white iron there was no expansion at all, and the casting gave a nearly uniform curve. But if silicon were introduced into the cast iron that would turn out the graphite, and lead to a diminution of density which could be proved experimentally by ascertaining the specific gravity. This diminution of density was accompanied by a marked expansion on the extensometer. Further, where an expansion is recorded there is also a heat evolution, and it could scarcely be expected that when a body is heated in this way expansion would take place in one direction only.

Mr. D. EWEN said a further point mentioned related to the purity of the antimony affecting their disagreement with the results of Dr. Wüst. The antimony-lead used was the purest obtainable, whereas the measure of purity of the antimony used by Dr. Wüst was not stated in his paper.

Professor TURNER added that the last thing their late Vice-President, Mr. Cookson, did only shortly before his death, was to provide him with that antimony as being the purest description furnished by his firm. The sample was, he believed, obtained at considerable trouble, and represented the very best commercial antimony which could possibly be supplied.

THE EFFECT OF SILVER, BISMUTH, AND ALUMINIUM UPON THE MECHANICAL PROPERTIES OF "TOUGH-PITCH" COPPER CONTAINING ARSENIC.

By FREDERICK JOHNSON, M.Sc., A.I.M.M.

INTRODUCTION.

MODERN specifications for wrought copper tubes, plates, rods, &c., are so stringent that it is desirable to know to what extent impurities are responsible for some of the failures of manufactured material when subjected to modern tests—failures which often result in the rejection of many tons of such material.

Very little work has hitherto been done on the subject, and even the work of Professor Roberts-Austen * was carried out under conditions quite incomparable with works-practice, and bore results the value of which is somewhat discounted by the nature of those conditions.

Many brands of pig copper, even when furnace-refined, are wholly unfit to undergo mechanical treatment because of the presence of impurities, and even amongst experts in the copper trade very little is known as to which impurities are desirable or which undesirable, and still less is known concerning the limiting proportion allowable of any single impurity, or concerning the variability of this proportion as influenced by the simultaneous presence of some other impurities. One has only to refer to published analyses of commercial copper material † to realise what a remarkable solvent power copper has for many impurities.

Professor Roberts-Austen ‡ employed a method of casting test-pieces containing measured quantities of impurities which

* Second Report to the Alloys Research Committee, Institute of Mechanical Engineers, 1893.

† *Ibid.*; also *Proceedings of the Institute of Civil Engineers*, 1902 and 1904.

‡ Second Report to the Alloys Research Committee.

was extremely ingenious. His object was to exclude all traces of oxygen from the copper, and with this end in view he used a crucible completely covered in. Luted in the lid were several inverted carbon cylinders (made by boring out the centres of arc-lamp carbons), and when the metal was molten he caused it to flow into these cylinders by merely inverting the crucible. As a cleverly-devised and admirably-executed piece of research work little fault can be found with it; but, unfortunately, the results as embodied in the report are of little value to the practical man. To show, for instance, that bismuth had a deleterious effect whilst arsenic had a beneficial effect on copper was only putting on record what had long been recognised amongst practical copper-metallurgists. The testing of these alloys at high temperatures proved very interesting, and it will be seen from Plate XXXI. of the Second Report that copper containing arsenic was far better than copper containing bismuth. But, unfortunately, the bismuth-copper alloy (0.1 per cent. bismuth) could not be worked, and so the material used in that research would never be met with in practice, viz. copper containing 0.1 per cent. bismuth (a very high proportion), without oxygen, and in the cast state. The author has endeavoured to come more into line with works-practice by introducing arsenic into the copper, and, as already mentioned, sufficient oxygen to produce a sound "tough-pitch" ingot capable of being *rolled*.

Reference to the work of Lawrie * will be made later, but he came to the conclusion that 0.005 per cent. bismuth was the limiting quantity allowable in *electrolytic* wirebar-copper required to be rolled.

Hampe † fixed the limiting quantities of bismuth at 0.05 per cent. for copper to be cold-worked and 0.02 for copper to be worked hot. The author's experience in practice has confirmed the fact that bismuth has a much more serious effect on the hot-working properties than on the cold-working properties of copper. but he would place 0.02 per cent. bismuth as the maximum allowable proportion in "tough-pitch" copper

* *American Institute of Mining Engineers Bulletin*, September 1909.

† *Zeitschrift für das Berg-, Hütten- und Salinen-Wesen im Preuss. Staate*, vol. xxii., 1874.

containing, say, 0.4 per cent. arsenic. Bismuth lower than this should be aimed at; in fact, 0.02 per cent. will make its presence felt even when accompanied by arsenic, if the copper has to receive very severe deformation at a red-heat, *e.g.* piercing billets for tube-drawing. Hampe's experiments included the investigation of the influence of bismuth protoxide (BiO) on copper, and of bismuth sesquioxide (Bi_2O_3) in addition to cupric oxide (CuO).

He found that metallic bismuth had more serious effects on the cold-working properties than the oxide, also that when cupric oxide was present cold-shortness was not nearly so pronounced. This is merely equivalent to saying that oxygen suppresses the ill effects of bismuth, a fact very generally known; but Hampe's experiments do not show, quantitatively, the amounts of oxygen, relative to the proportion of bismuth present in copper, necessary to preserve that delicate equilibrium where red-shortness and cold-shortness are both avoided and resistance to bending maintained.

The work of E. A. Lewis* has come nearer to the problem which the author has attacked than any other which has come to his notice.

Lewis made 6-lb. ingots from electrolytic copper, melted under charcoal (to *exclude oxygen*), adding the impurity, and pouring. It was in the absence of oxygen that the effect of the impurities was examined, and this fact is sufficient to impair the usefulness of his results from the general standpoint of works-practice.

The regulation of the quantity of oxygen in copper is the keynote of all copper refining. It is the presence of a well-defined proportion of oxygen in the form of cuprous oxide, forming a copper-cuprous oxide eutectic, which enables copper to be cast free from blowholes. It seems that when oxygen is present, other gases are less soluble in molten copper; when oxygen is absent, or is present in insufficient quantity, the copper dissolves other gases, such as hydrogen and carbon monoxide, which are insoluble in the copper when solid, and, being rejected during the process of solidification, cause internal porosity and external ridges or excrescences.

* *Journal of the Society of Chemical Industry*, 1903, vol. xxii., No. 24, p. 1351.

Moreover, impurities in copper have their ill effects—particularly on the hot and cold-working properties—notably checked by the presence of oxygen.

Lewis rolled his ingots into sheets at a red-heat, and judged of their quality by observing their appearance after rolling. The rolled sheets were then annealed and submitted to a bending test. No record appears of the amount of reduction in thickness, nor of the nature of the bending test.

With regard to the effect of bismuth, he came to the conclusion that arsenic, to a certain extent, neutralised its injurious effect, while tin, manganese, and aluminium intensified that effect. His results are given herewith.

TABLE I.—*Effect of Bismuth on Copper in the Presence of As, Sn, Mn, and Al.**

No.	Impurity added.	Rolling Test.	Bending Test, Annealed.
2	0·1 per cent. bismuth	Cracks very badly at edge	Will not bend, breaks off short.
7	0·6 per cent. arsenic 0·1 per cent. bismuth	Cracks at edge, but not so bad as without arsenic	Bends fairly well.
8	0·6 per cent. arsenic 0·05 per cent. bismuth	Rolls fairly well	Bends well.
12	0·5 per cent. tin 0·05 per cent. bismuth	Will not roll.	.....
14	0·5 per cent. manganese 0·05 per cent. bismuth	Will not roll.	.....
17	0·5 per cent. aluminium 0·05 per cent. bismuth	Will not roll.	.....

In the same article Lewis states:—

“Bismuth is far more dangerous than lead, but it is never present in modern copper in the free state in anything like this quantity (0·2 per cent.): its action is interesting as illustrating the effect of metals of the first group on copper (*i.e.* metals which separate out round the copper crystals in the free state, such as lead and bismuth). The presence of 0·002 per cent. bismuth is sufficient to make pure electrolytic copper, which has been melted, brittle, when there is no Cu_2O present.”

* E. A. Lewis, *Engineering*, December 4, 1903.

In explanation of the results given above, he goes on to say:—

"In pure copper, lead and bismuth are insoluble in the crystals of the copper; the presence of arsenic forms an alloy with a portion of the copper, which is probably a solution of arsenide of copper in copper, and this alloy, which separates out round the crystals of copper as a network, is capable of holding any bismuth and lead in solid solution, and thus rendering them harmless. Another point which will be noticed is that those metals which dissolve in the crystals of copper, such as manganese and aluminium, cause the bismuth and lead to have a far more injurious effect; in fact, the plates split up the centre after one passage through the rolls. The probability is that these metals, by dissolving in the copper, completely destroy the slight cohesion there may exist between the crystals of copper and the fine network of bismuth or lead surrounding them."

The statement that "arsenic forms an alloy with a portion of the copper" is only another way of describing the cast-structure of a solid solution where "cores" of the purer material are involved by a network of impurer material. Re-heating such a metal results in the disappearance of the "cores," the annealed metal showing a crystalline structure of greater uniformity (see Figs. 1 (GG) and 3 (GG)).*

In 1896 Arnold and Jefferson† published an article on "The Influence of Small Quantities of Impurities on Gold and Copper."

With reference to bismuth in copper, they state that "the bismuth (0.5 per cent.) occurs not only as cell walls but in isolated irregular globules." Under higher powers they observed that "the sectional bismuth meshes each present a remarkably definite and straight plane of cleavage."

Peters‡ in his chapter on "The Refining of Copper" discusses the results of various workers in his eminently practical way. The remarks which bear chiefly on the subject are as follows:—

* See also *Journal of the Institute of Metals*, vol. iii. No. 1, 1910, Plate II. Figs. 7 and 10.

† *Engineering*, February 7, 1896.

‡ "Principles of Copper Smelting," Peters, p. 470 *et seq.*

"Copper alloyed with 0·05 per cent. bismuth under precautions against any formations of cuprous oxide is both cold-short and red-short."

He writes of arsenic as one of the most universal of the impurities that contaminate refined copper, though not so injurious as either bismuth or antimony.

He classes silver as a harmless impurity, and gives as harmful impurities "bismuth, antimony, arsenic, tellurium, and selenium." "These five elements," he says, "follow the copper with such persistency that they not only impair its quality seriously in those cases where the pig copper is refined *direct* (without previous electrolytic treatment), but even make it difficult for the electrolytic process itself to produce copper of the highest standard."

He concludes from Hampe's experiments that "the defective qualities noticed in over-poled copper are due either to the absorption of certain of the gases evolved in poling (namely, hydrogen and carbon monoxide), or to the reduction to the metallic—and, consequently injurious—condition of certain of the oxides and salts of the impurities which were in the metallic copper, such as oxide of bismuth, antimonate of bismuth, arsenate of lead, &c., or to both of these conditions combined." Again: "... Injury to the copper resulting from over-poling must, in ordinary cases, be looked for, not in the diminution of its contents of cuprous oxide, nor yet in the absorption of reducing gases, but rather in some change in the chemical condition of the minute proportion of impurities still present in the copper, which are comparatively harmless so long as the metallic copper still contains 0·7 per cent. cuprous oxide (or whatever amount of this substance has been found necessary in each particular instance). It seems probable that certain of these dissolved foreign oxides and salts, which are comparatively harmless, while still remaining in the oxidised form, become injurious when reduced to the metallic condition."

"So long as there is considerable amount of cuprous oxide present, these oxidised compounds are protected; but when the proportion of cuprous oxide becomes diminished to the (variable) limit already mentioned, the reduction of the foreign oxides to metal begins, and the quality of the copper com-

mences to suffer, even before the absorption of the injurious reducing gases becomes demonstrable."

The foregoing "long-established theory" appears to the author to be no longer tenable. Microscopic examination of the structure of many specimens of copper containing various impurities has induced the belief that the action of these impurities, considered in their relation to copper containing cuprous oxide, or to copper in the absence of cuprous oxide, is mainly of a physical character. For instance, copper will hold arsenic in solid solution,* whether cuprous oxide be present or not; copper containing silver up to 0.3 per cent. together with 0.4 per cent. arsenic requires no more cuprous oxide to render it "tough-pitch" than pure electrolytic copper. Also, cuprous oxide is only necessary in refined arsenical copper to ensure its freedom from reducing-gases and the consequent production of sound castings (assuming all other impurities to be absent).

So that, with regard to these two impurities, viz. arsenic and silver, all theories which attribute their harmlessness to the fact that they exist as salts or oxides can no longer be entertained.

The case of bismuth seems to be somewhat different. The author has confirmed the results of Arnold and Jefferson, in that bismuth separates quite definitely and resolutely from the crystals of copper in the form of metallic bismuth if cuprous oxide be absent. However, unlike silver, bismuth requires more oxygen to render the copper "tough-pitch" the greater its proportion; so that 0.05 per cent. bismuth requires 0.05 per cent. oxygen, while 0.10 per cent. bismuth requires 0.08 per cent.

In this case, therefore, it is obvious that bismuth owes its comparative harmlessness to the fact that it has entered into some form of combination with oxygen. For the sake of clearness the author proposes to regard this as an oxidised form of bismuth, although proof of its identity is not yet complete.

But, as will be shown later, it is to the physical condition in which bismuth exists that the improvement in mechanical properties of the copper containing it is largely due. If, as in

* As dissolved Cu_3As .

copper free from oxygen, bismuth occurs as brittle plates and films, enmeshing the crystals of copper, and eliminating the natural cohesiveness exhibited between them, when directly contiguous to one another (as in pure electrolytic copper), then the copper is quite inferior when submitted to mechanical treatment. But if, as in "tough-pitch" copper, bismuth occurs oxidised as minute globules, isolated from each other by similar globules of cuprous oxide, as existent in the copper-cuprous oxide eutectic, then the copper will not suffer so much in its mechanical properties as in the former case.

There will always be, however, a diminution of quality, as regards hot-working, in "tough" arsenical copper containing 0.02 per cent. bismuth or more, as compared with similar copper free from bismuth, since whatever the composition of the bismuth constituent may be, it must exist in a fluid or pasty state at the forging-temperature.

Regarding arsenic, Hiorns* remarks that 0.1 per cent. to 0.2 per cent. shows a structure similar to that of commercial copper. He leaves out of account the presence of cuprous oxide in all refined commercial copper, which is so readily discernible under the microscope, and which so completely modifies the structure. He states that the structure "consists of rough, dark-coloured polygonal grains, with a suggestion of a eutectic nature, very soft and difficult to get entirely free from scratches: these are bounded by a lighter-coloured and harder material, which I assume to be a solid solution of arsenic in copper, because it is structureless. This solid solution probably varies in arsenic content in the different alloys."

As mentioned on page 167, when discussing the work of Lewis, this structure is nothing more nor less than that of a single solid solution exhibiting a "cast" structure, where "cores" of copper-rich material are involved by a network of arsenic-rich material.

Some experiments made by Hiorns† to gauge the effect of small quantities of impurities on the malleability of copper are interesting, but, like those of Lewis, were carried out in the absence of oxygen.

* Faraday Society, April 13, 1904.

† *Journal of the Society of Chemical Industry*, July 1906, p. 8.

He found that 0·5 per cent. arsenic only slightly diminished the malleability, whilst 0·5 per cent. bismuth rendered copper quite unworkable. 0·2 per cent. arsenic, in the presence of 0·2 per cent. bismuth, diminished the brittleness caused by bismuth (proportion not stated) alone.

Regarding the single effect of bismuth on the micro-structure, Hiorns* states: "Copper with small percentages of bismuth consists of polygonal grains, the cell walls of which are of a light copper colour, and in the 0·4 per cent. to 0·5 per cent. alloys, a thin dark line, probably rich in bismuth, runs through the centre of these walls."

He observed that when the metal was broken the line of fracture followed the direction of the thin dark line in the boundaries. The author's own observations do not quite agree with the foregoing. See notes on microstructure later.

Stahl† finds that arsenic has the effect of increasing the tensile strength, malleability, and ductility, of reducing the solvent power of copper for reducing-gases, of increasing its hardness, and of neutralising the ill effect of bismuth. He gives the mechanical properties of copper containing 0·3 per cent. to 0·35 per cent. as follows:—

Maximum stress	14 to 14·6 tons per square inch.
Elongation	33 ,, 44 per cent.
Contraction of area . . .	47 ,, 62 ,,

He contends that when arsenical copper is frequently heated, volatilisation of arsenic ensues and leads to deterioration of the copper.

Bengough and Hill‡ record some very instructive experiments on the strength of rolled bars (containing up to 1·9 per cent. arsenic) and their behaviour under heat-treatment. In Table II. the tensile tests of these bars—as rolled—are given. They had considerably more reduction in the hot-rolling than had the author's bars, but it will be seen that their tensile strength nowhere exceeds that of the latter, until 0·75 per cent. arsenic has been exceeded (compare with bars E, EE, and V¹, Series A, Table VII. p. 188).

* Faraday Society, April 4, 1905.

† *Metallurgie*, 1909, vol. vi. p. 610.

‡ *Journal of the Institute of Metals*, vol. iii. No. 1, 1910.

TABLE II.*

	Maximum Stress, Tons.	Yield Point.	Elongation on 2 Inches.
	Per Cent.	Per Cent.	Per Cent.
Bar A (0.04 per cent. As) . . . }	15.5 15.6	6 6.5	58 58
Bar C (0.25 }	15.7 15.8	8.8 10.2	52 48
Bar D (0.75 }	15.7 15.6	6.3 6.1	59 55
Bar E (0.94 }	16.5 16.6	8.8 8.5	56 53
Bar B (1.94 }	17.0 16.8	6.7 6.4	62 62

The above bars were prepared from electrolytic copper and metallic arsenic. The latter was added to the molten copper in a crucible furnace. The resulting alloy was poled and poured into an iron ingot-mould, giving a round ingot 3 feet by 3 inches in diameter. The ingots were rolled hot and then drawn cold in one pass of $\frac{3}{64}$ inch. The finished bars were 1 inch in diameter by 15 feet. Tensile test-pieces measured 9 inches with 2 inch parallel by $\frac{1}{2}$ inch diameter.

Another important inference is that any variation in the percentage of arsenic between 0.04 per cent. and 0.75 per cent. is unaccompanied by any effect on the mechanical properties as revealed by static tests, so that variations in this respect in the author's bars—due to the frequent necessity of re-casting, and seldom exceeding 0.1 per cent.—are negligible.

Regarding the effect of cuprous oxide, Hampe† found that cuprous oxide had no effect upon the strength or malleability of pure copper until 0.45 per cent. was reached, when a very slight diminution of tenacity was recorded. Ductility, in the cold, was not affected until 0.9 per cent. was reached. Beyond 0.9 per cent. the quality of the copper suffered more and more

* "The Constitution and Properties of Copper-Arsenic Alloys." Bengough and Hill, *Journal of the Institute of Metals*, vol. iii. No. 1.

† *Zeitschrift für das Berg-, Hütten- und Salinen-Wesen im Preuss. Staate*, 1873-6.

as the proportion of Cu_2O was increased (0.9 per cent. Cu_2O = 0.10 per cent. oxygen).

Heyn* found that copper and cuprous oxide were completely miscible when fused, but were mutually insoluble in the solid state. He fixed the eutectic point at about 20°C . below the melting-point of pure copper, the concentration being 3.4 per cent. cuprous oxide. Alloys with less oxygen than the eutectic proportion consist of crystals of pure copper surrounded by eutectic; those containing more oxygen consist of dendrites of cuprous oxide, surrounded by eutectic. It is the presence of these dendrites in excess which, in the author's belief, renders even the purest copper red-short.

OBJECTS OF THE RESEARCH.

The objects of this research, then, have been to discover the effects of certain impurities on copper in the "tough-pitch" condition, *i.e.* copper containing just sufficient oxygen to ensure a level surface and soundness in the casting and to confer on it those physical and mechanical properties in which, otherwise, it would be deficient. Since nearly all copper used for locomotive tubes, firebox-plates and stays, or for sheet and wire, which is not required for electrical purposes, contains a small quantity of arsenic, and since all such copper is generally required to undergo some process of mechanical work at a red heat, the author determined to use for his experiments pure electrolytic copper containing an approximately constant proportion of arsenic.

The ingots were all subjected to hot-rolling, being all of the same size, and all—with one exception (bar U)—reduced to the same size of rod in one heat. It was upon this hot-wrought material that mechanical tests were carried out with the object of ascertaining the influence of the impurities on—

1. Tensile strength and extensibility.
2. Resistance to bending.
3. Resistance to alternating stresses in the Arnold machine.
4. Malleability.

* Report of the Royal Technical Testing Institute, Charlottenburg, 1900, p. 315.

METHOD OF PREPARING THE INGOTS.

It may at once be said that this initial stage of the work was the most delicate, the most trying, and by far the most important. Many trials or exploratory meltings were made before the final and most satisfactory method was found. The author had the choice of three methods of casting, viz.:—

1. Casting in sand moulds.
2. Casting in closed chill moulds.
3. Casting in open chill moulds.

After trying all three, the third was chosen as the most convenient, the most reliable and approximating most nearly to works-practice. Here, again, several trials were made with different types of mould, the ordinary cast-iron ingot mould possessing several disadvantages, viz.:—

1. Tendency to rust when not in use (rust causing ingots to boil in the mould and become porous).

2. Difficulty of turning out the hot ingot when cast, ingots perfectly uniform in thickness from end to end being difficult to turn out of a solid ingot mould.

3. A solid ingot mould such as mentioned would be clumsy to handle.

At last the following device was chosen:—

The mould, which was to receive the metal, was formed by four pieces of iron $1\frac{1}{4}$ inch square; two pieces 13 inches long and two pieces 3 inches long, arranged on a flat brick tile so as to form a space $6\frac{1}{2}$ inches by $1\frac{1}{4}$ inch by $1\frac{1}{4}$ inch.

The brick tile was used because (1) on account of its low heat conductance it allowed the metal to remain molten for a short time before solidification commenced, so minimising risks of cold-setting; (2) it was superior to the cast-iron top of the furnace, because the latter could never be expected to be quite free from rust or scale.

It should be mentioned that casting in sand moulds would have been much too troublesome, would have necessitated the use of more metal, and would have obviated the possibility of judging the pitch of the ingot from the appearance of the surface—a most essential feature of the work.

Closed chill moulds also presented the last-named difficulty, in addition to the grave risks of "cold-setting" and porosity. The mould used by Lawrie, although ingeniously contrived, presents all the above-mentioned difficulties, besides producing very small ingots. He used a large gate feeding into an iron mould, which was formed by clamping together two halves, each having four longitudinal grooves, coinciding to form four "fingers" circular in section, 12 inches long by $\frac{9}{16}$ inch diameter (see Fig. 1 of Bulletin). Very few, if any, of his ingots were free from porosity, whilst "cold sets" were frequently encountered.

With the form of mould used by the author, not a single ingot exhibited either of these defects, when all the above-mentioned conditions were strictly observed.

The methods of melting and bringing to pitch were similar to those adopted by Lawrie.*

It should be mentioned here that the method of testing the pitch of the copper by taking small samples, although forming the best *modus operandi* yet known to the author, is by no means infallible, and it was found necessary to rely upon the appearance of the ingot when set as the ultimate criterion to signify its suitability or unsuitability for further investigations. If it showed a marked longitudinal depression, it was rejected as being "under-pitch"; if it showed a ridge or "spewed," it was rejected as being "over-pitch." Only ingots exhibiting a surface practically dead level were submitted to rolling and subsequent tests. It may readily be understood that a large number of abortive experiments were made.

As regards the form in which the metal entered the crucible, (1) the copper was introduced as cathode copper of 99.98 per cent. purity; (2) arsenic was added in the form of an alloy of cathode copper and metallic arsenic (of 99 per cent. purity); (3) the other impurities, viz. aluminium, bismuth, and silver, were all used in the purest forms obtainable, the silver being purified by the author.

The contents of the crucible were always well stirred with an iron poker, well clayed to prevent the introduction of iron to the copper.

It was found advisable to have the metal quite hot to ensure fluidity when pouring and to avoid "skulls" of metal in the crucible and the dangers of "cold-setting" in the mould. This was not always an easy matter, as the operation of bringing to pitch often took a considerable time, and to replenish the fire in the furnace entailed lowering the temperature of the crucible and its contents. Often it became necessary to close up the furnace (an ordinary wind furnace 9 inches square) in order to regain lost heat, by which time the contents of the crucible had invariably gone "under-pitch," and the testing had to be repeated. Care had to be exercised in handling the clay crucible, as repeated withdrawals from the furnace by means of tongs had a tendency to chip off the edges, and start cracks.

DATA REGARDING ROLLING OF INGOTS.

The ingots, after casting, were reheated to a bright red heat, and rolled in eight passes to rods measuring 4 feet by $\frac{1}{2}$ inch diameter, finishing at a dull red heat. These rods were immediately quenched in water in order to remove scale, and to toughen them.

The rods were numbered, and pieces cut from them for the various mechanical tests; pieces for analysis were cut as close as possible to the test-pieces. The bending test was performed on a part of the remaining portion of each rod.

MECHANICAL TESTS.

1. *Bending Test.*—The piece of rod was fastened upright in a vice, with 2 inches projecting from the jaws. This was hammered over to an angle of 90° , and then taken out and doubled in the jaws of the vice until a crack appeared. If no crack appeared, the doubling over was completed through the entire angle of 180° . The rods were tested as rolled.

The only bars to fail in this test were G (under-pitch) and V (over-poled).

2. *Alternating-stress Tests.*—These were very kindly carried out by Professor J. O. Arnold, D.Met., Head of the Department of Applied Science of the University of Sheffield, in his

patented alternating-stress testing machine. Lengths of rod 6 inches long were turned down to $\frac{3}{8}$ inch diameter, and tested as rolled. These were fastened rigidly in the stationary die of the machine in a vertical position, and were submitted to alternating stresses to and fro, $\frac{3}{8}$ inch from either side of the vertical, by a slotted arm worked by an electrically-driven eccentric. The number of alternations was automatically recorded by a mechanical register, the release of a spring by the operator stopping the action of the latter so soon as the specimen broke. The rate of alternating was 650 per minute. Two strokes of the moving arm constituted one alternation to and fro.

The length of specimen fixed in the die was such that the specimen could be reversed and a duplicate test taken, the duplicate end being outside the zero of stress of the first test.

The value of this test for copper cannot be too highly rated, as it reveals in a very trustworthy manner any defect in the "pitch" of the metal, not only in the low number of alternations which "under-pitch" copper will endure, but also in the appearance of the fracture. "Tough-pitch" copper shows a very pale, silky surface, the final line of fracture (at right angles to the direction of the stresses, and occurring right through the centre of the bar in homogeneous metal) being very fine, measuring only 0.01 inch in breadth in the middle. This line is darker in colour than the remaining area of the fractured surface, and, when slight excess of cuprous oxide is present, is a little broader. More cuprous oxide results in the appearance of one or two subsidiary lines on either side of the central line, while an unusual excess of cuprous oxide broadens the central line very considerably.

A record of the tests, including the appearance of the fractured surfaces, is given in Table III.

It will be seen from these figures and from the curve (Diagram No. 4) that the effect of bismuth is to lower the resistance of arsenical copper whether "tough-pitch" or "under-pitch," with the one exception of bar KKI containing 0.05 per cent. bismuth whose strength in this respect is higher than any of the bars tested in this research.

3. *Tensile Tests*.—These were carried out in the Civil

Engineering Department of the University of Birmingham. Full details are given in Table IV A.

Tests for Malleability.—Pieces of the bars as rolled were turned down to $\frac{3}{8}$ inch diameter, and lengths measuring 0.75 inch were cut from these. It was found advisable to turn down to this diameter, as some of the bars containing bismuth were so defective after hot-rolling as to necessitate this reduction in order to get a core of sound metal.

The test-piece, measuring 0.75 inch by 0.375 inch diameter, was then placed under a hammer and subjected to light blows until a crack appeared at the edge. The punishment is very great. Modern specifications for fire-box stays often include this test; the dimensions of the test-pieces being 1 inch by 1 inch diameter, and, to pass the test, the hammered disc must not show a crack or flaw after hammering from 1 inch to 0.375 inch, *i.e.* 62.5 per cent. reduction in thickness. It will be seen from the results in Table V. that not one of the author's test-pieces failed, the best surviving a reduction of over 90 per cent., in spite of the fact that the ratio of length to diameter was very much greater than in the case of tests of commercial material. For results see Table V.

5. *Hot-working Properties.*—These were judged by the appearance of the rods after hot-rolling, and a classification was adopted whereby these properties could be fairly accurately appraised.

Any material falling in Classes 1 to 4 may be rolled at a bright red heat. (The point which determines the classifying of metal between 1 and 4 is the comparative susceptibility to cracking during rolling.) Class 5 may be regarded as the critical stage between material fit for rolling at a bright red and material unfit for such treatment.

Material in this class would be better rolled at a slightly lower temperature, *i.e.* between a bright red and a dull red heat. Material falling into any class lower than this may be considered unfit for hot-rolling, since reduction could only be started at a dull red heat; even then the resulting metal would show cracks; moreover, re-heating would be necessary before bringing it down to the required gauge. One of the most important points in this connection is, that material

TABLE III.—*Alternating-stress Tests in the Arnold Machine.*

Mark on Bar.	Impurity, per Cent.	Oxygen, per Cent.	Condition of Ingot.	No. of Alternations.	Texture.	Position of Line of Fracture and Appearance.	Subsidiary Lines.
R .	Nil	0.089	Level	164	Silky	Central, broad (0.03 inch)	Present.
E .	"	0.066	"	190	"	Central, fine (0.01 inch)	Absent.
EE .	"	0.060	"	177	"	"	"
V .	"	0.052	"	190	"	"	"
V .	"	0.182	Elevation	122	Dry	Central, flaw	Present.
U .	"	0.091	Depression	152	Rough	Central, broad (0.03 inch)	"
W .	"	0.162	"	160	Dry	"	"
F .	0.042 Ag	0.056	Level	180	Silky	Central, fine (0.01 inch)	Absent.
F .	0.087 "	0.075	Depression	161	"	Central (0.02 inch)	"
FF .	0.094 "	0.063	Level	187	"	Central, fine (0.01 inch)	"
G .	0.185 "	0.200	Depression	120	Dry	Not central (0.08 inch)	Strongly present.
GG .	0.175 "	0.058	Level	174	Silky	Central, fine (0.01 inch)	Absent.
H .	0.292 "	0.095	Depression	174	"	"	"
HH .	0.292 "	0.048	Level	180	"	"	"
K .	0.052 Bi	0.079	?	186	"	Central (0.02 inch)	Trace.
KK1 .	0.051 "	0.055	Level	201	"	Central, fine (0.01 inch)	Absent.
K2 .	0.074 "	0.084	Depression	172	"	Nearly central (0.02 inch)	"
KK2 .	0.073 "	0.068	Level	186	"	Central, fine (0.01 inch)	"
K3 .	0.094 "	0.155	Depression	178	"	Central (0.03 inch)	Trace.
KK3 .	0.097 "	0.084	Level	178	"	Central, fine (0.01 inch)	Absent.
K4 .	0.122 "	0.127	Depression	158	"	Central (0.03 inch)	Present.
KK4 .	0.124 "	0.073	Level	164	"	Central, fine (0.01 inch)	Absent.
N .	0.023 Al and Fe	0.026	"	199	"	"	"
Z .	0.420 Al and Al ₂ O ₃	Nil	Depression	189	"	"	"

TABLE IV A. — *Tensile Tests on Rolled Bars.*

Test No.	Mark on Specimen.	Length of Parallel Part of Specimen.	Dimensions in Inches.		Limit of Elasticity.	Breaking Load.		Extension, per Cent.		Impurities, per Cent.		Remarks.
			Diam.	Area.	Tons per Sq. In.	Lbs. per Sq. In.	Tons per Sq. In.	On whole Length of 3 Ins.	On 1 In. at Fracture.	Oxygen.	Added Impurity.	
1276	R	3 inches	0.375	0.110	6.9*	33,500	14.92	39		0.089	Nil	Broke outside gauge-points.
1275	E	"	0.377	0.112	...	35,150	15.70	41	52	0.066	"	
1275	E.E.	"	0.375	0.110	6.7*	35,300	15.75	51	65	0.060	"	
1307	V ¹	"	0.380	0.113	6.37*	...	15.75	38	55	0.052	"	
1253	V	"	0.379	0.113	...	32,650	14.58	34	47	0.182	"	
1285	U	"	0.500	0.196	5.54*	35,170	15.70	47	70	0.091	"	
1259	W	"	0.378	0.112	...	34,200	15.25	45	54	0.162	"	Central flaw (unoxidised) due to gases of a "reducing" nature. Over-poled.
1308	F ¹	"	0.374	0.110	6.54*	...	15.75	48	62	0.056	0.042 Ag	
1266	F	"	0.379	0.113	...	36,050	16.10	33	50	0.075	0.087	
1309	F.P.	"	0.374	0.110	7.27*	...	15.92	43	61	0.063	0.094	
1257	G	"	0.385	0.116	...	36,050	16.10	39	53	0.200	0.185	
1272	G.G.	"	0.375	0.110	8.9*	37,900	16.93	39	49	0.058	0.175	
1258	I	"	0.380	0.113	...	36,400	16.25	41	56	0.095	0.292	
1310	I.I.I.	"	0.374	0.110	8.18*	...	16.44	47	57	0.048	0.202	
1274	K ¹	"	0.375	0.110	5.3*	33,800	15.05	50	65	0.079	0.052 Bi	
1312	K.K.1	"	0.374	0.110	6.36*	...	15.71	44	68	0.055	0.051	
1305	K.2	"	0.376	0.111	7.48*	...	15.78	40	53	0.084	0.074	
1313	K.3	"	0.374	0.110	5.90*	...	15.82	46	60	0.068	0.073	
1271	K.3	"	0.375	0.110	...	33,800	15.10	37.5	+	0.155	0.094	Broke outside gauge-points.
1314	K.K.3	"	0.375	0.110	4.73*	...	16.09	48	61	0.084	0.097	
1311	K.4	"	0.378	0.112	5.03*	...	15.71	45	54	0.127	0.122	
1315	K.K.4	"	0.373	0.109	5.23*	...	16.18	42	53	0.073	0.124	
1260	X	"	0.379	0.113	...	34,450	15.40	44	57	0.026	0.014 Al	
1261	Z	"	0.379	0.113	...	35,500	15.85	43	57	Nil	0.320	

* No definite yield point; the figures given are for the first noticeable elongation.

TABLE IV B.—Tensile Tests on Material after Cold Working and Annealing.

Test No.	Mark on Specimen.	Length of Parallel Part of Specimen.	Dimensions—Inches.			Limit of Elasticity, Tons per Sq. In.	Breaking Load, Tons per Sq. In.	Extension per Cent.		Impurities.		Description of Fracture.
			Breadth.	Thick-ness.	Area.			On Whole Length of 3 In.	On 1 In. at Fracture.	Oxygen, per Cent.	Added Impurity, per Cent.	
1342	EE	3 inches	0.641	0.208	0.134	8.2	14.55	35	57	0.060	Nil	Shear silky.
1343	F	"	0.632	0.218	0.138	8.3	14.72	36	55	0.056	0.042 Ag	" "
1344	FF	"	0.632	0.209	0.132	9.1	15.31	43	59	0.063	0.094 "	Fishtail
1345	GG	"	0.630	0.206	0.130	8.9	15.50	46	59	0.058	0.175 "	Shear
1346	HH	"	0.634	0.216	0.137	8.1	14.85	37	53	0.048	0.292 "	" "
1347	KK1	"	0.625	0.211	0.132	8.3	15.22	42	59	0.055	0.051 Bi	Fishtail
1348	KK2	"	0.625	0.214	0.134	7.9	14.72	40	53	0.068	0.073 "	" "
1349	KK3	"	0.631	0.210	0.132	7.9	14.90	33	48	0.084	0.097 "	" "
1350	KK4	"	0.635	0.215	0.136	7.4	14.98	35	51	0.073	0.124 "	Shear

which has once been broken down at a red-heat is thenceforward far more amenable to further hot-forging (after re-heating) than the original material. For instance, bar KK4 showed a bad surface appearance after the hot-rolling process,

TABLE V.—*Cold Malleability Tests on Material as Rolled*
Test-Pieces, 0.75 inch by 0.375 inch diameter.

No. of Test-piece.	Impurity.	Oxygen.	Reduction in Thickness.	Remarks.
	Per Cent. Nil.	Per Cent.	Per Cent.	
R . .		0.089	89.34	No arsenic present. Slight circumferential cracks all round disc.
E . .	..	0.066	90.67	Arsenic present. Uncracked.
EE . .	..	0.060	91.00	.. Incipient crack.
V ¹ . .	..	0.052	90.67	.. Uncracked.
V . .	..	0.182	66.67	.. Incipient split due to "over-poling" flaw.
U . .	..	0.091	89.34	.. Incipient crack.
W . .	..	0.162	78.67	.. Several incipient cracks.
F ¹ . .	0.042 Ag	0.056	90.67	.. Uncracked.
F . .	0.087 ..	0.075	90.67	.. ..
FF . .	0.094 ..	0.063	86.67	.. Slight crack.
G . .	0.185 ..	0.200	81.34	.. Incipient crack.
GG . .	0.175 ..	0.058	90.09	.. Uncracked.
H . .	0.292 ..	0.095	88.00	.. Incipient crack.
HH . .	0.292 ..	0.048	82.94	.. ..
K1 . .	0.052 Bi	0.079	88.89	.. Uncracked.
KK1 . .	0.051 ..	0.055	89.34	.. Incipient crack.
K2 . .	0.074 ..	0.084	85.14	.. ..
KK2 . .	0.073 ..	0.068	89.34	.. ..
K3 . .	0.094 ..	0.155	78.67	.. Slight crack.
KK3 . .	0.097 ..	0.084	83.34	.. Incipient crack.
K4 . .	0.122 ..	0.127	86.67	.. Slight crack.
KK4 . .	0.124 ..	0.073	90.13	.. Uncracked.
X . .	0.014 Al	0.026	92.00	.. Incipient crack.
Z . .	0.320 ..	Nil.	78.67	.. Several deep splits.
	0.100 Al ₂ O ₃			

but the rolled material could then be hammered out at a red-heat, to a knife-edge, without showing any signs of cracking.

The author has endeavoured to elucidate this point and to advance a theory in explanation of the phenomenon elsewhere.*

* *Chemical and Metallurgical Engineering*, October 1910.

Effect of Cold Work.—For this purpose those bars were selected which had exhibited "tough-pitch" qualities in all the preceding operations, in order to place on record their suitability for cold-working, and their mechanical properties in the tensile testing-machine. The cold-working consisted in hammering out flat the hot-rolled material (8 inches by $\frac{1}{2}$ inch diameter) without annealing, until it measured $\frac{1}{4}$ inch thick by $\frac{1}{8}$ inch wide. All the bars selected, with the exception of the KK bars, underwent this treatment without showing any signs of cracking at the edges. The flat strips, measuring $8\frac{1}{4}$ inches by $\frac{1}{8}$ inch by $\frac{1}{4}$ inch (the total linear extension only amounted to 3 per cent., whereas the lateral extension was approximately 50 per cent.), were then passed through cold rolls set at $\frac{1}{4}$ inch distance apart, reversed and passed through a second time, without altering the gauge of the rolls. This was done in order to render the thickness more uniform, the centres of the hammered strips being slightly in excess of $\frac{1}{4}$ inch. When finished, the strips were uniformly $\frac{1}{4}$ inch thick from end to end. They were then annealed in one batch at a dull red heat for half-an-hour and quenched in water.

These strips were then machined down into tensile test-pieces, with parallel length measuring 3 inches by $\frac{5}{8}$ inch by $\frac{3}{16}$ inch.

The results are given in Table IVB.

METHODS OF ANALYSIS.

Copper.—1 gramme dissolved in dilute nitric acid, evaporated to a syrup, cooled, and diluted, 2 cubic centimetres H_2SO_4 added, made up to 100 cubic centimetres with distilled water and electrolysed, using the rapid method as described by Price and Humphries.* The copper was deposited in about an hour, the greatest difficulty being experienced in expelling the last traces, the concentration of the electrolyte being a great factor in the rate of deposition. Electrolysis was stopped and the cathode removed, washed in distilled water and alcohol and dried, only when a sample pipetted from the solution showed no trace of copper when submitted to the following test:—

* *Journal of the Society of Chemical Industry*, 1909, p. 117.

The sample contained in a test tube, and measuring about 5 cubic centimetres, was just neutralised with strong ammonia, then just acidified with glacial acetic acid, cooled and tested with one spot of a dilute solution of potassium ferro-cyanide. The slightest pink coloration indicated that all of the copper had not been removed from the electrolyte, and electrolysis was allowed to proceed until a sample showed no pink coloration. This test reveals the presence of 0.0001 gramme copper in 100 cubic centimetres, of which 5 cubic centimetres are taken for testing, *i.e.* 0.000005 gramme.

In cases where the copper contained silver or bismuth, it was found that these were deposited on the cathode; silver completely, bismuth only in part.

Bismuth always discoloured the deposit. The deposits containing bismuth were redissolved in HNO_3 and the bismuth determined separately by a double precipitation with ammonia, and subtracted from the original weight of the deposit, in order to get the true weight of copper.

At first it was attempted to separate silver and bismuth from a bigger sample of copper (10 grammes) by precipitating with NaCl in the case of silver, or with ammonia in the case of bismuth, making up the filtrates to 1000 cubic centimetres in a litre flask and pipetting off 100 cubic centimetres for electrolysis. After many experiments this method was abandoned, owing to slight inaccuracies in the capacities of the flasks and pipettes, also to the interfering action of chlorine in the electrolyte in the case of NaCl and to the presence of such a large proportion of ammonium nitrate (due to a double precipitation) in the case of ammonia.

As above mentioned, the silver was entirely deposited with the copper, when no previous separation had been effected, and so it was only necessary to subtract from the weight of the deposit the weight of silver as determined on a separate sample. At least two determinations were made in all the assays, and the mean taken.

Arsenic.—1 gramme of sample in form of fine drillings. This was placed in a flask of 500 cubic centimetres capacity and distilled with 150 cubic centimetres of a solution of ferric and calcium chlorides in strong hydrochloric acid. For details

of this method, as adopted by the author with slight modifications, see Beringer's "Text-book of Assaying."

A blank distillation with 1 gramme of pure electrically-deposited copper was carried out to determine the amount of arsenic present in the ferric chloride mixture.

Oxygen.—20 grammes of copper. This was in the form of small rectangular pieces $\frac{1}{2}$ inch by $\frac{1}{4}$ inch by about $\frac{1}{32}$ inch thick, which had been hammered out from the original bar, dipped in dilute nitric acid to remove scale, washed in ammonia to remove grease and film of oxide, finally in alcohol, and then carefully dried. A current of hydrogen generated in a Kipp's apparatus was passed over this copper, heated to a red-heat in a silica bulb by means of a Teclu burner. The hydrogen was first passed through (1) a mercuric chloride solution, (2) a strong potash solution, (3) strong sulphuric acid, and (4) a drying column of calcium chloride. Hydrogen was passed for one hour, the flame removed, and the stream of gas continued until the bulb was cold. Atmospheric air was then aspirated through the bulb, and its loss of weight determined on the balance. The loss of weight represented the oxygen contained in 20 grammes of copper.

It was found in the case of copper containing bismuth that some of the latter was volatilised and recondensed in a cooler part of the bulb. Arsenic also exhibited this tendency.

Silver.—10 grammes. Dissolved in dilute nitric acid, silver precipitated by means of sodium chloride; precipitate washed, dried, ignited and cupelled with 1 gramme of sheet assay lead; resulting bead weighed. This method gave very accurate results.

Bismuth.—10 grammes dissolved in dilute nitric acid, neutralised to clear blue with ammonia, brought to boiling, allowed precipitate to settle and filtered. Redissolved precipitate in nitric acid, reprecipitated with ammonia, and filtered. Washed precipitate and redissolved in nitric acid: passed sulphuretted hydrogen. Sulphide of bismuth precipitated, filtered off, washed, dissolved in dilute nitric acid, precipitated with ammonia, filtered, washed, dried, ignited, and weighed as Bi_2O_3 . The H_2S precipitation was rendered necessary by the presence of traces of iron.

Aluminium.—10 grammes dissolved in dilute nitric acid, precipitated with ammonia, redissolved precipitate and reprecipitated with ammonia, brought to the boil, filtered, washed, dried, ignited and weighed as Al_2O_3 .

In Table VI. are given complete analyses of all the bars.

TABLE VI.—*Analyses.*

No. of Bar.	Copper.	Arsenic.	Oxygen.	Impurity.	Total.
	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.
R . .	99·905	Nil.	0·089	...	99·994
E . .	99·592	0·344	0·066	...	100·002
EE . .	99·565	0·410	0·060	...	100·035
V ¹ . .	99·570	0·361	0·052	...	99·983
V . .	...	0·300	0·182	...	...
U . .	99·515	0·383	0·091	...	99·989
W . .	99·425	0·427	0·162	...	100·014
				Ag.	
F ¹ . .	99·613	0·300	0·056	0·042	100·011
F . .	99·480	0·363	0·075	0·087	100·025
FF . .	99·427	0·417	0·063	0·094	100·001
G . .	99·274	0·373	0·200	0·185	100·032
GG . .	99·315	0·453	0·058	0·175	100·001
H . .	99·328	0·305	0·095	0·292	100·020
HH . .	99·258	0·423	0·048	0·292	100·021
				Bi.	
K ¹ . .	99·499	0·366	0·079	0·052	99·996
KK ¹ . .	99·460	0·420	0·055	0·051	99·986
K ² . .	99·365	0·464	0·084	0·074	99·987
KK ² . .	99·452	0·403	0·068	0·073	99·996
K ³ . .	99·420	0·355	0·155	0·094	100·024
KK ³ . .	99·424	0·390	0·084	0·097	100·003
K ⁴ . .	99·345	0·400	0·127	0·122	99·994
KK ⁴ . .	99·320	0·468	0·073	0·124	99·985
				Al.	
X . .	99·440	0·526	0·026	Al 0·014 Fe 0·009	100·015
Z . .	99·340	0·260	Nil.	{ 0·42 Al 0·320 Al ₂ O ₃ 0·100 }	100·02

OBSERVATIONS.

TABLE VII., SERIES A ("BLANK BARS").

1. All the "tough-pitch" arsenical specimens show improved mechanical properties over the arsenic-free "tough-

pitch" electrolytic specimen R, which underwent exactly the same treatment.

2. Bar V has been tested in order to place on record the ill effects of "over-poling." It will be noticed that, although the ingot showed the usual ridge, due to the escape of reducing-gases, yet the proportion of oxygen present is sufficient to render the ingot "under-pitch." This is due to the fact that the metal in the crucible was first allowed to go over the pitch, and then air was employed to bring it back. It will be seen how unsuccessful that effort was, since the admission of excess oxygen was insufficient to eliminate the reducing-gases. This confirms the experience of Messrs. Hofman, Hayden and Hallowell.*

3. The presence of arsenic in the ingots tends to lower the proportion of oxygen necessary to make the copper "tough-pitch." Without arsenic, the copper requires about 0.08 per cent. oxygen; with arsenic, about 0.06 per cent. seems to be sufficient. These figures only hold good for the size of casting used in this research.

4. Electrolytic specimen R is inferior in cold malleability to any of the "tough" arsenical specimens.

5. Slow-cooling after hot-rolling does not confer such toughness—as indicated by resistance to alternating stresses—as quenching. Compare E and V¹ (quenched) with EE (slowly cooled). All the other bars used in this research were quenched immediately after rolling.

6. Carrying the hot-rolling beyond a certain limit seems to act rather in raising the elastic limit than in improving the tensile strength. Bar U was finished at a higher temperature, and after undergoing less work than any of the others. Compare bars U and V¹, together with the results of tests carried out by Messrs. Bengough and Hill (Table II.).

7. There seems to be no advantage in adding arsenic as metallic arsenic, in which form it was added to all the above arsenical bars except V¹, to which it was added in the form of arsenious oxide.

* *Transactions of the American Institute of Mining Engineers*, vol. xxxviii, p. 77 et seq.

TABLE VII., SERIES A.—Blank Experiments on Bars containing Arsenic and Oxygen.

Mark on Logot.	Appearance of Logot.	Mechanical Treatment.	Arsenic, per Cent.	Oxygen, per Cent.	Impurity, per Cent.	$\frac{1}{2}$ -Inch Bar Bend Test.	Tensile Strength, Tons per Sq. In.	Elongation, per Cent. on 3 In.	Limit of Elasticity, Tons per Sq. In.	No. of Alternations (Arnold).	Order of Hot Malleability.	Reduction in Cold Malleability Tests, per Cent.
R	Level. " Tough-pitch "	Rolled hot to $\frac{1}{2}$ in. diameter and quenched	Nil	0.089	Nil	180° unbroken	14.92	39	6.9	164	1	89.34
E	Level. " Tough-pitch "	" " " "	0.344	0.066	"	"	15.70	41	"	190	2	90.67
EE	Level. " Tough-pitch "	Rolled hot to $\frac{1}{2}$ in. diameter and slowly cooled	0.410	0.060	"	"	15.75	51	6.7	177	2	91.00
V	Level. " Tough-pitch "	Rolled hot to $\frac{1}{2}$ in. diameter and quenched	0.361	0.05	"	"	15.75	38	6.37	190	2	90.67
U	Depression. Slightly " under-pitch "	Rolled hot to $\frac{1}{2}$ in. diameter and quenched	0.383	0.091	"	"	15.70	47	5.54	152	2	89.34
V	Ridge in centre. Over-poled	Rolled hot to $\frac{1}{2}$ in. diameter and quenched	0.300	0.184	"	135° broken	14.58	34	"	122	2	66.67
W	Depression and two cavities. " Under-pitch "	" " " "	0.427	0.162	"	180° unbroken	15.25	45	"	160	2	78.67

TABLE VII., SERIES B. — Experiments on Bars containing Silver in varying Proportions, Arsenic and Oxygen being in Approximately Constant Proportions.

Mark on Ingot.	Appearance of Ingot.	Mechanical Treatment.	Arsenic, per cent.	Oxygen, per cent.	Silver, per Cent.	$\frac{1}{2}$ -Inch Bar Bend Test.	Tensile Strength, Tons per Sq. In.	Elongation per cent. on 3 Inches.	Limit of Elasticity, Tons per Sq. In.	No. of Alterations (Arnold)	Order of Hot Malleability.	Reduction in Cold Malleability Tests, per Cent.
F	Depression and cavity. Slightly "under-pitch"	Roll ed hot to $\frac{1}{2}$ inch diameter and quenched	0.363	0.075	0.087	180 unbroken	16.10	33	...	161	2	90.67
G	Depression and cavity. Quite "under-pitch"	"	0.373	0.200	0.185	45 broken	16.10	39	...	120	2	81.34
H	Depression. Slightly "under-pitch"	"	0.365	0.065	0.292	180 unbroken	16.25	41	...	174	3	88.00
F	Level. "Tough-pitch"	"	0.300	0.056	0.042	"	15.75	48	6.54	180	2	90.67
FF	Level. "Tough-pitch"	"	0.417	0.063	0.094	"	15.42	43	7.27	187	2	86.67
CG	Level. "Tough-pitch"	"	0.453	0.058	0.175	"	16.43	39	8.9	174	2	90.09
HH	Level. "Tough-pitch"	"	0.423	0.048	0.280	"	16.44	47	8.18	180	3	82.94

TABLE VII., SERIES B (SILVER).

1. Bars F and H were either "under-pitch," or, at any rate, were not at the highest possible state of "tough-pitch"; bar G was hopelessly "under-pitch." Duplicate ingots (FF, GG, and HH) were therefore made.

2. Bar GG exhibits greater strength and elasticity, reduced ductility, and resistance to alternating tests by reason of the fact that it was finished rolling at too low a temperature (incipient-red instead of dull-red).

3. Silver in the presence of arsenic does not impair the hot-working properties up to at least 0.175 per cent. It increases the tensile strength and raises the elastic limit, but hardly affects the ductility, or resistance to alternating-stresses (see curves, Diagrams 1 and 2). It does not seem to influence the proportion of oxygen necessary to make the copper "tough-pitch," the tendency being, if anything, to slightly lower this proportion.

4. Where oxygen is in slight excess of that required for the "tough-pitch" stage, the tensile strength, elongation and resistance to alternating-stresses are all lowered, but in the cold-malleability tests the presence of a slight excess of oxygen coincides with slightly better malleability (in the case of bar G there is a considerable excess of oxygen).

TABLE VII., SERIES C (BISMUTH).

1. Bars K1, K2, K3, and K4 were slightly "under-pitch." They exhibited slight depressions in the cast ingot, indicating that they were rich in oxygen, and the results of the mechanical tests were very conflicting. Bars KK1, KK2, KK3, and KK4, are repetitions of them, and, fortunately, were all cast in the "tough-pitch" state.

2. The effect of bismuth on the hot-working properties is detrimental even in the presence of arsenic, but up to 0.05 bismuth, if 0.3 to 0.4 per cent. arsenic be present, the effect is far from ruinous.

3. Hot-working improves the copper in the direction of suitability for receiving further mechanical treatment. For instance, bar KK4, containing 0.12 per cent. bismuth, was infinitely better suited for further hot or cold working than the

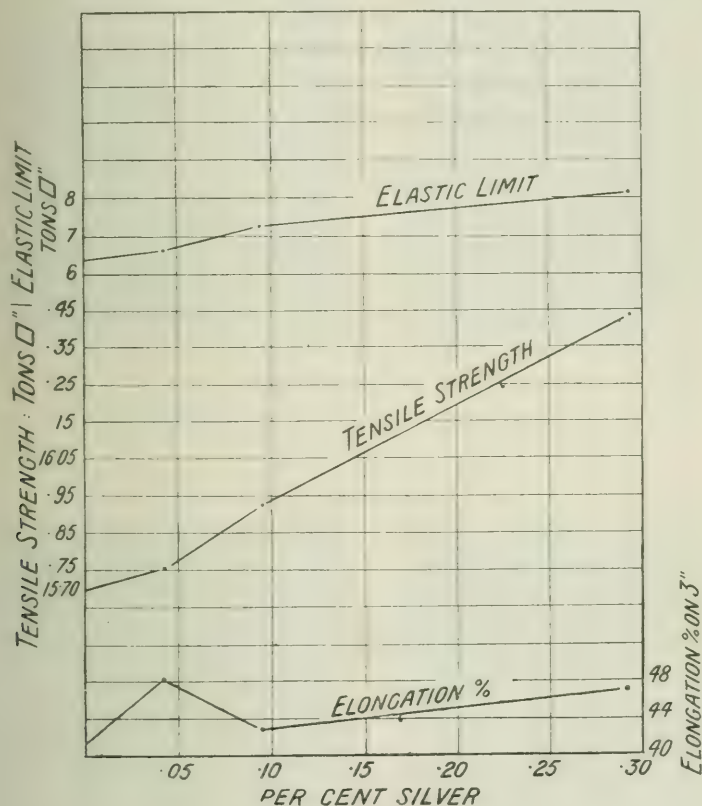


DIAGRAM 1.

same metal had been in the "cast" condition. The cold-working properties of all the bars were satisfactory, bar KK1 (0.05 per cent. bismuth) giving better results in all the tests (except malleability test) than the standard arsenical bar E.

4. Bismuth has the effect in "tough-pitch" arsenical copper of raising the tensile strength and extensibility, but of lower-

ing the elastic limit and resistance to alternating stresses (see curves, Diagrams 3 and 4).

5. An increase in the percentage of bismuth demands a similar slight increase in the percentage of oxygen in order that the ingot may be "tough-pitch."

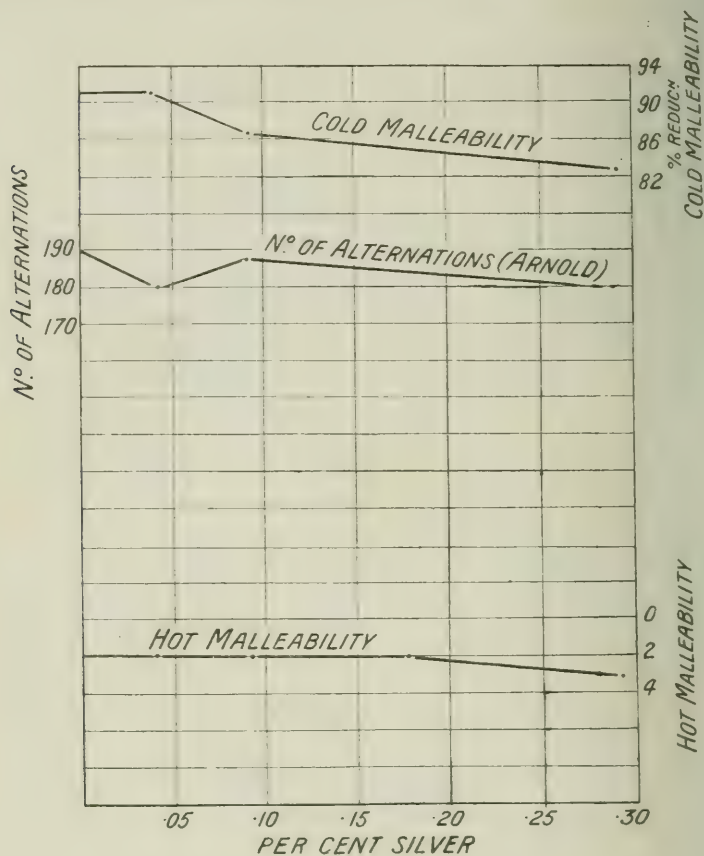
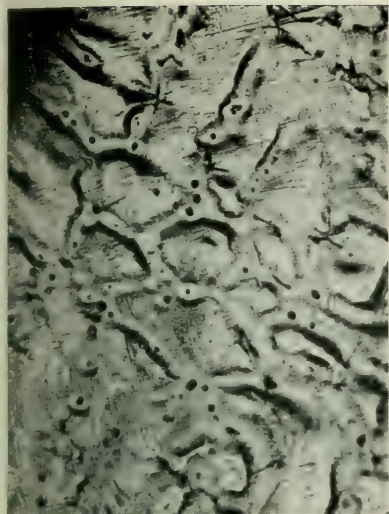


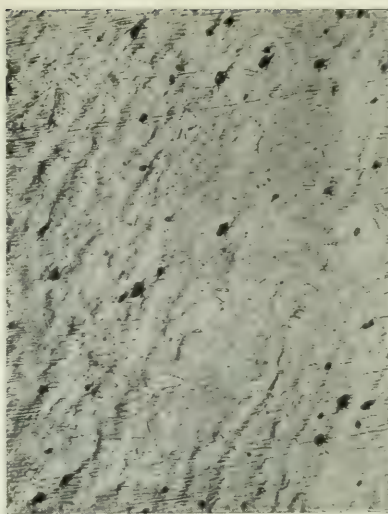
DIAGRAM 2.

6. Where the oxygen is in excess of this critical quantity, the copper has better hot-working properties, but its mechanical properties in the cold (particularly resistance to alternating stresses and tensile strength) are seriously affected. Compare K1 and KK1. In every instance in the cold-malleability



No. 1 (GG).—Magnified 300 diameters.

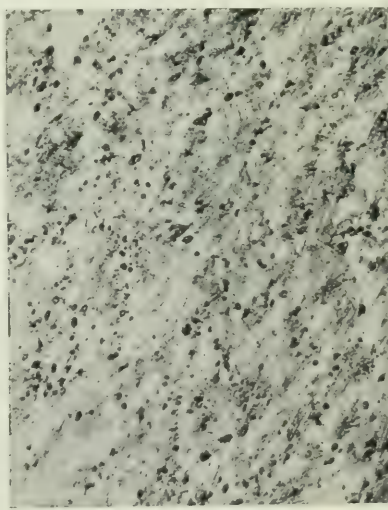
Cu . . .	99.315 per cent.	} as cast.
As . . .	0.453 "	
Ag . . .	0.175 "	
Oxygen . .	0.058 "	



No. 2 (GG).—Magnified 300 diameters.
Same as No. 1 after rolling hot.

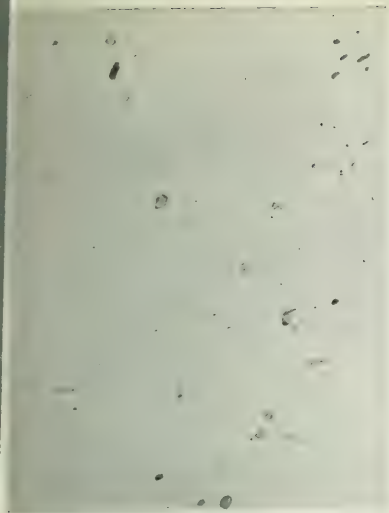


No. 3 (GG).—Magnified 300 diameters.
Same as No. 2 after cold-working
and annealing.

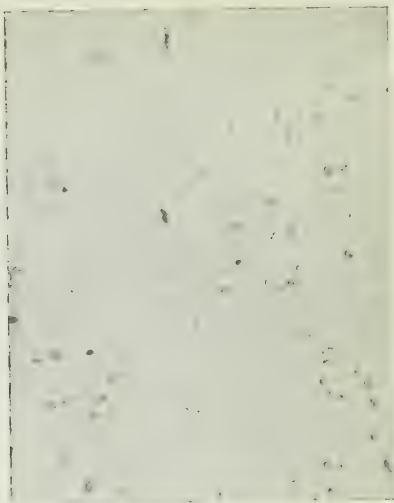


No. 4 (G).—Magnified 300 diameters.

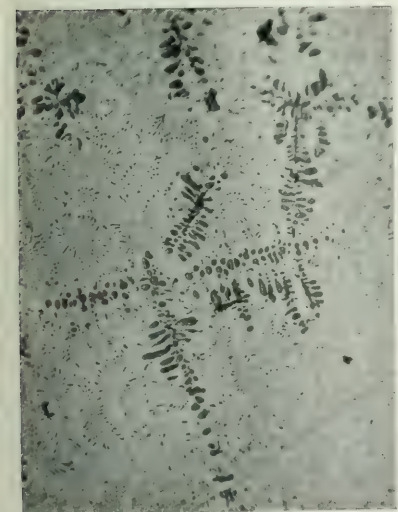
Cu . . .	99.274 per cent.	} after rolling hot.
As . . .	0.373 "	
Ag . . .	0.185 "	
O . . .	0.200 "	



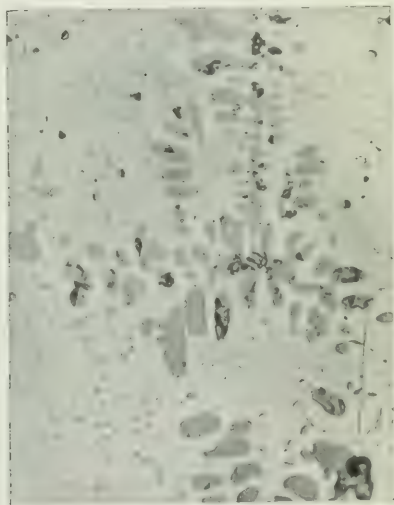
No. 5 (V¹).—Magnified 300 diameters.
Unetched. Oxygen, 0·052 per cent.
"Tough-pitch."



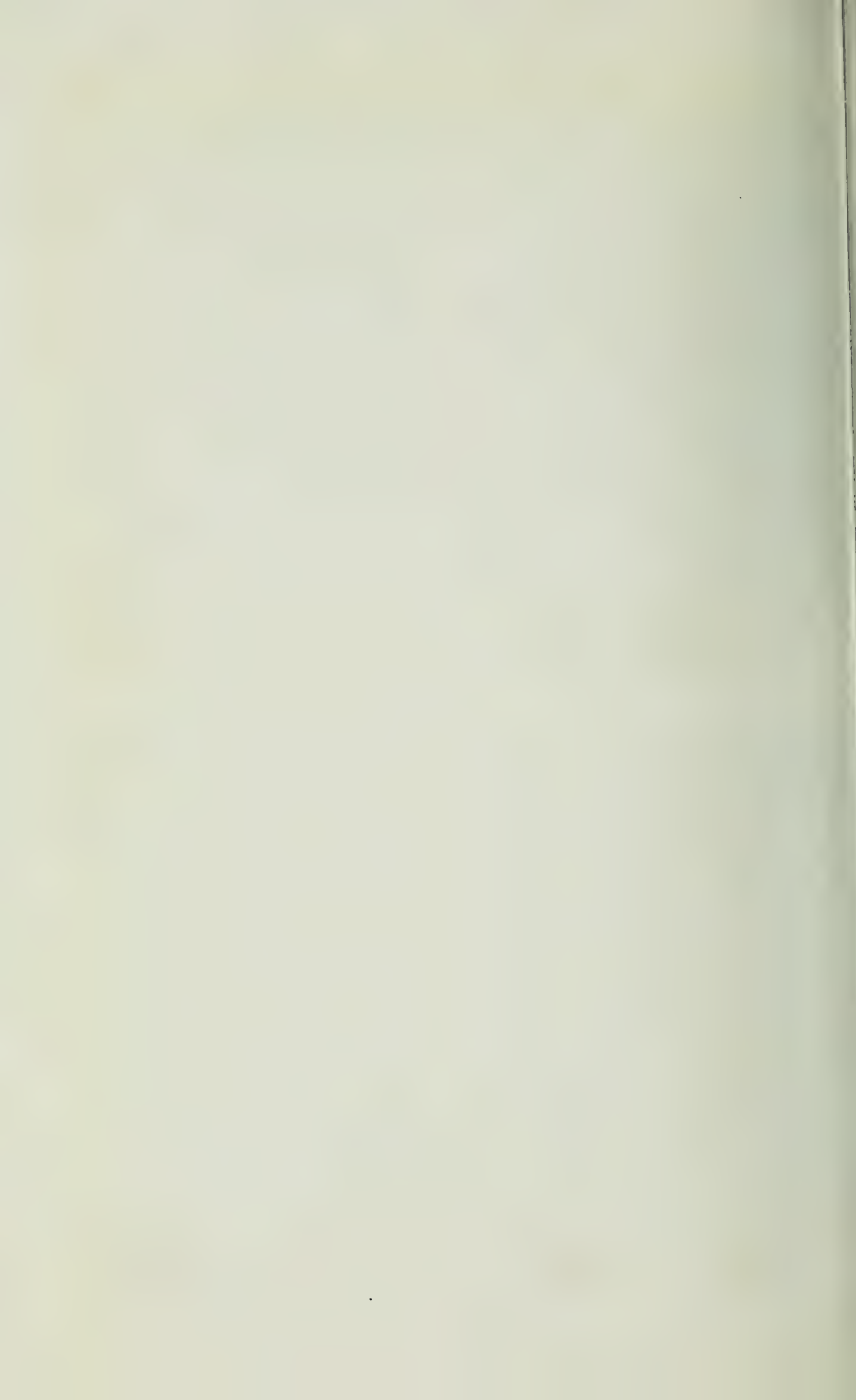
No. 6 (V).—Magnified 300 diameters.
Unetched. Oxygen, 0·182 per cent.

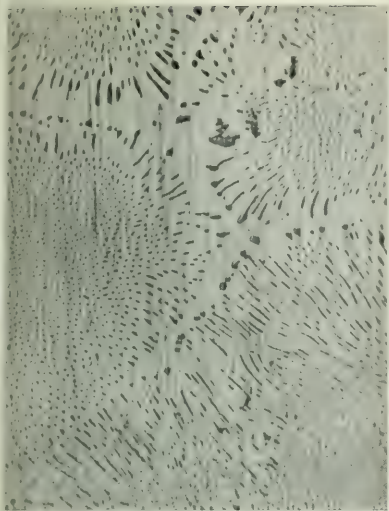


No. 7 (P).—Magnified 100 diameters.
Furnace sample before "poling."
Unetched.



No. 8 (P).—Magnified 300 diameters.
Same as No. 7 (P). Unetched.

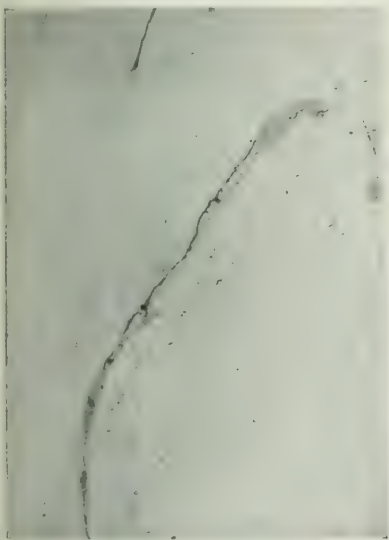




No. 9 (P).—Magnified 300 diameters.
Furnace sample during "poling."
Unetched.



No. 10 (P).—Magnified 300 diameters.
Furnace sample after "poling"
"Tough-pitch." Unetched.

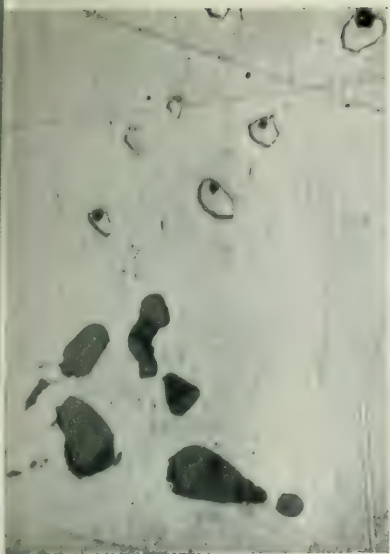


No. 11 (Q).—Magnified 400 diameters.
Copper containing 0.05 per cent.
bismuth and trace of sulphur.
Furnace-cooled. Unetched.

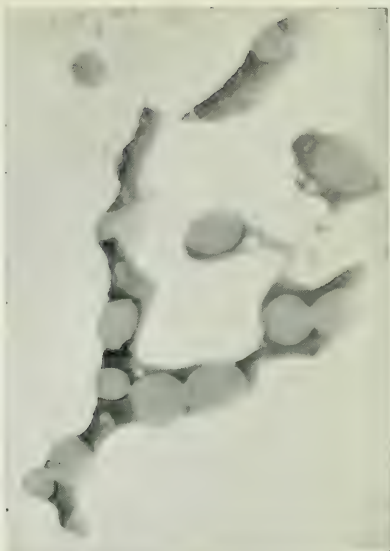


No. 12 (Q).—Magnified 1000 diameters.
Copper containing 0.10 per cent.
bismuth and a trace of sulphur.
Furnace-cooled. Unetched.

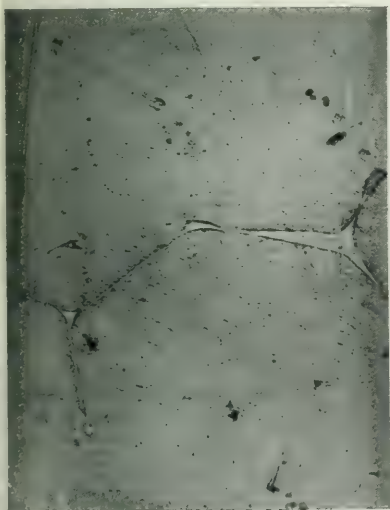




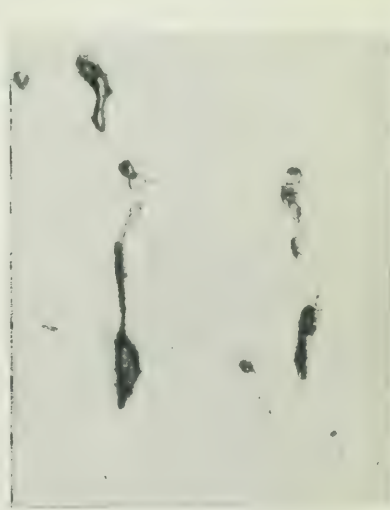
No. 13 (Q).—Magnified 1000 diameters.
Copper containing 0·5 per cent.
bismuth and 0·08 per cent. oxygen.
Slowly cooled. Unetched.



No. 14 (Q).—Magnified 1000 diameters.
Copper containing 0·5 per cent.
bismuth and 0·11 per cent. oxygen.
Slowly cooled. Unetched.



No. 15 (Q).—Magnified 400 diameters.
Copper containing 0·5 per cent. bis-
muth and 0·24 per cent. arsenic.
Furnace-cooled. Etched in am-
monia.



No. 16 (Q).—Magnified 400 diameters.
Copper containing 0·5 per cent.
bismuth and 1·0 per cent. arsenic.
Furnace-cooled. Etched in hydro-
fluoric acid.

TABLE VII, SERIES C.—Experiments on Bars containing Bismuth in varying Proportions, Arsenic in Approximately Constant Proportion, and sufficient Oxygen to render them "Tough-Pitch."

Mark on Ingot.	Appearance of Ingot.	Mechanical Treatment.	Arsenic, per Cent.	Oxygen, per Cent.	Bismuth, per Cent.	$\frac{1}{2}$ -Inch Bar Bend Test.	Tensile Strength, Tons per Sq. In.	Elongation, per Cent. on 3 Inches.	Limit of Elasticity, Tons per Sq. Inch.	No. of Alternations (Arnold).	Order of Hot Malleability.	Reduction in Cold Malleability Tests, per Cent.
K1	Slight depression. Slightly "under-pitch"	Rollled hot to $\frac{1}{2}$ inch and quenched	0.366	0.079	0.052	180° unbroken	15.05	50	5.3	186	5	88.89
K2	Barely level. Slightly "under-pitch"	"	0.454	0.084	0.074	"	15.78	40	7.48	172	5 to 6	85.14
K3	Deep depression and cavity. "Under-pitch"	"	0.355	0.155	0.094	"	15.10	37.5	"	178	5	78.07
K4	Deep depression. "Under-pitch"	"	0.400	0.127	0.122	"	15.71	45	5.63	158	7	86.07
KK1	Level. "Tough-pitch"	"	0.420	0.055	0.051	"	15.71	44	6.36	201	5 to 6	89.34
KK2	Level. "Tough-pitch"	"	0.403	0.008	0.073	"	15.82	46	5.9	186	6	89.34
KK3	Level. "Tough-pitch"	"	0.390	0.084	0.097	"	16.09	48	4.73	178	7	89.48
KK4	Level. "Tough-pitch"	"	0.408	0.073	0.124	"	16.18	42	5.23	164	8	90.13

tests, a slight increase in the oxygen-content above the "tough-pitch" requirement coincides with slightly reduced malleability.

This is the reverse of what happened in the case of the bars containing silver.

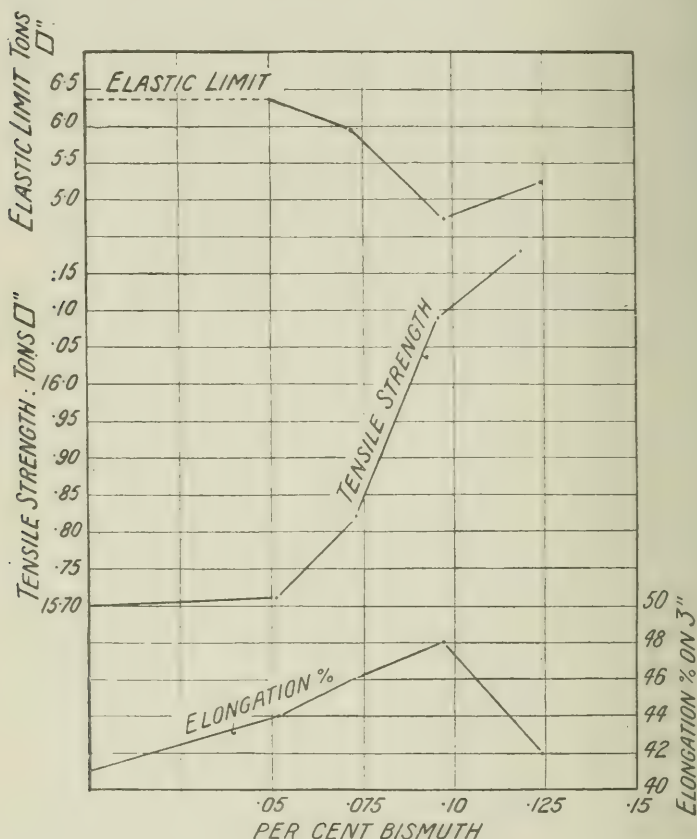


DIAGRAM 3.

Note.—The author has since demonstrated by experiments similar to those detailed in this thesis, that pure electrolytic copper in the "tough-pitch" condition, and free from arsenic, is unfit for rolling hot if it contains 0.02 per cent. bismuth. Such copper would behave worse when submitted to hot-

working than either of the author's bars K1 and KK1 (containing 0.05 per cent. bismuth).

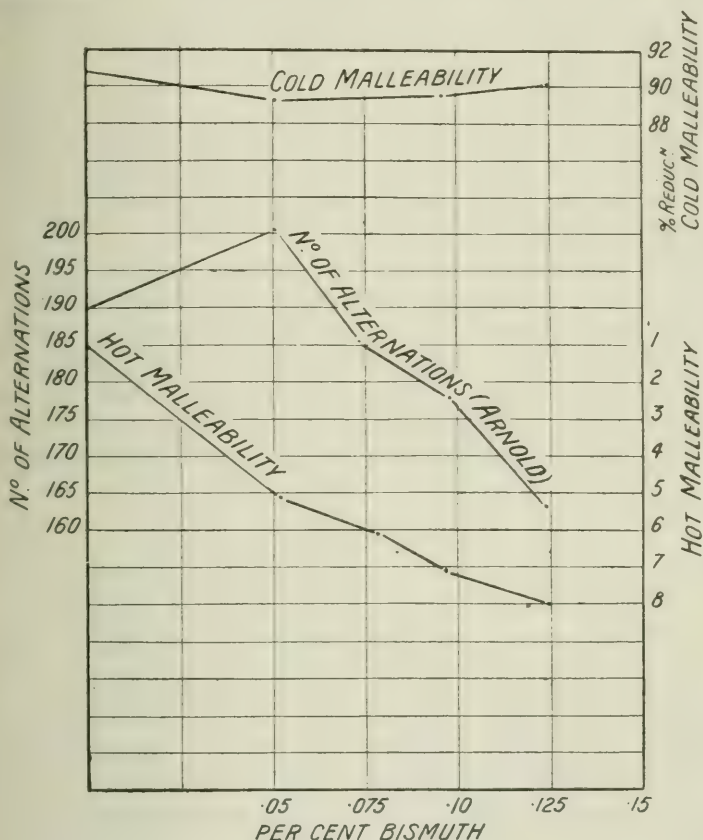


DIAGRAM 4.

TABLE VII., SERIES D (ALUMINIUM).

1. Bar X represents arsenical copper, which has been nearly deoxidised by the aid of aluminium. Its hot-working properties are in nowise inferior to those of the standard "tough-pitch" bars E, EE, and V¹, but its tensile strength is lower, its ductility and resistance to alternating stresses are slightly higher. This tends to show that, with a lower proportion of

oxygen present than that present in "tough-pitch" copper, the metal loses slightly in tensile strength, but gains in toughness and ductility. This could only have been shown by employing a means of reducing cuprous oxide which did not introduce reducing-gases into the metal.

2. Bar Z illustrates the disastrous effects of using too much aluminium for this purpose. The surface of the ingot sank to an extent which illustrates that the presence of aluminium in arsenical copper to be used for casting in open moulds (*e.g.* for rolling into sheet) is prohibitory.

Quite apart from this influence, however, there is the additional and insurmountable evil as evidenced by a destruction of the hot-working properties. Although the ingot survived hot-rolling, the resulting material was in a deplorable condition, the surface being defective from end to end. Evidently aluminium and arsenic together in copper are very bad friends, although each of these elements alone has beneficial effects.

TABLE IVB.—*Tensile Tests on Cold-worked Specimens.*

1. The effects of cold-working and annealing have been to lower the tensile strength of all the bars, and, with the exception of Bar GG, they all show inferior extensibility in comparison with the specimens as rolled. The recovery in extensibility of Bar GG can only be due to the fact, as already explained (p. 190), that the hot-rolling was finished at a lower temperature than the other bars, this initial stiffening of the material being removed by annealing. It is noteworthy that the strength conferred by this low-finishing temperature has persisted beyond the stages of cold-working and annealing, thus enabling the metal to have greater strength and extensibility than any of this series.

2. Although there is greater irregularity in these results than in the results of the tests on the "as rolled" specimens, it will be seen that the influences of silver and bismuth persist and are exerted in the same directions as before (see Table VII., Series B and C), *viz.* :—

TABLE VII., SERIES D.—Experiments on Bars containing Arsenic in Constant Proportion and Aluminium in Varying Proportions.

Mark on Ingot.	Appearance of Ingot.	Mechanical Treatment.	Arsenic, per Cent.	Oxygen, per Cent. (as Cu_2O).	Aluminium, per Cent.	$\frac{1}{2}$ -Inch Bar Bend Test.	Tensile Strength, Tons per Sq. In.	Elongation per Cent. on 3 Inches.	Limit of Elasticity, Tons per Sq. In.	No. of Alterations (Arnold)	Order of Hot Malleability.	Reduction in Cold Malleability Tests, per Cent.
N	Level. Similar to "tough-pitch" copper	Rolled hot to $\frac{1}{4}$ inch diameter and quenched	0.526	0.026	0.021	180° unbroken	15.40	44	...	199	2	92.00
Z	Deep depression. Does not "scale" like copper	"	0.300	Nil	0.320 Al_2O_3 0.10	"	15.85	43	..	189	8	78.67

Influence of silver: Increases tensile strength, but scarcely affects extensibility or elasticity.

Influence of bismuth: Increases tensile strength, increases extensibility (which, however, again decreases, as the proportion of bismuth rises), reduces elasticity.

MICROSCOPY.

The main things to be said of the structure of the actual bars employed in this research are that the effects of hot-rolling and cold-working and annealing are to produce structures markedly distinct from one another, and from that of the material as cast.

Micrograph No. 1 GG shows the structure of a typical "tough-pitch" arsenical ingot as cast (GG). The "cores" are very distinct, and are due to the rapidity of cooling, the crystalline composition being variable from each centre of crystallisation to each boundary. Notwithstanding this lack of local uniformity, the ingot, taken *en masse*, is very uniform in composition. The little black areas which are seen dotting the light-coloured arsenic-rich cell-walls are cuprous oxide; these appear under the microscope as small, rounded areas of a sky-blue colour.

Micrograph No. 2 GG shows the structure of the same material as in No. 1. but after the process of "hot-rolling." Note that the structure is closer and finer, but more confused. This represents the intermediate stage between the "core" structure of the cast material and the development of a homogeneously crystalline structure of greater uniformity of composition. The small black areas are cuprous oxide.

Micrograph No. 3 (GG) shows the structure of the same material after cold-working and annealing. Homogeneity has now been attained, and the "cores" have completely given place to a clearly-defined polyhedral structure.

Micrograph No. 4 G shows the structure of Bar G (Table VII., Series B), which is of similar composition to Bar GG (see Micrograph No. 2), but it is "under-pitch" (0.20 per cent. oxygen). The presence of this excess oxygen is easily

seen on comparing with Micrograph No. 2, the "oxidules" * being very much more numerous. What is also noticeable in this micrograph is the incipient formation of "wrought crystals," or the crystals due to the breaking-up process of hot-rolling. These do not appear so distinctly in Bar GG, since the rolling in that case was carried a little too far, and any such crystals formed at a high temperature became distorted when the rolling was continued at a temperature lower than dull red. Also the excess cuprous oxide would favour their formation.

Micrograph No. 5 V¹ shows the polished but unetched surface of Bar V¹ containing 0.05 per cent. oxygen ("tough-pitch" proportion). Blue "oxidules" show against a salmon-pink background.

Micrograph No. 6 V shows the polished but unetched surface of Bar V containing 0.182 per cent. oxygen ("under-pitch" as regards proportion of oxygen). The number of "oxidules" is here very much greater than in No. 5.

The next four micrographs are samples of copper taken from a refining furnace, and are intended to illustrate the changes which occur in the condition of the cuprous oxide as the operation of "poling" proceeds.

Micrograph No. 7 P represents the condition of the metal before "poling" is commenced. Note that no free crystals of copper occur, cuprous oxide being in large excess and appearing in two forms, viz. (1) as massive "dendrites" of light-blue cuprous oxide, which are first to solidify; and (2) as eutectic-crystals of copper and cuprous oxide, which form the entire matrix of the alloy.

Micrograph No. 8 P shows one of the "dendrites" of cuprous oxide under higher magnification. Some of the cuprous oxide has fallen out from its bed in places during polishing, leaving black cavities.

Micrograph No. 9 P shows the structure of the alloy after "poling" has proceeded for some time. The whole charge at this stage was of eutectic composition. All the cuprous oxide dendrites have disappeared.

* The author prefers to identify these cuprous oxide globules under the abbreviation "oxidules."

Micrograph No. 10 P shows the structure of the copper at the "tough-pitch" stage, when "poling" has been stopped and the metal is ready for ladling.

Note that the eutectic has been considerably reduced in amount, crystals of copper having largely replaced it. These crystals have been first to solidify, and have pushed out the "mother-liquor," which, growing progressively richer in oxygen, has reached the composition where it will yield up no more free copper, and then solidifies—practically instantaneously—as the copper-cuprous oxide eutectic, surrounding the pure copper crystals of earlier solidification. The freezing point of the copper crystals is given by Heyn* as $1105^{\circ}\text{C}.$ and that of the eutectic as $1084^{\circ}\text{C}.$

The following micrographs illustrate the condition of bismuth in copper (1) alone. (2) with oxygen. (3) with arsenic. The endeavour has been to promote the segregation of bismuth by cooling very slowly from the molten state to the completely solid state, and with this object in view most of the samples were allowed to cool out with the furnace, the crucible being so fixed as to avoid falling over when the fuel burnt low.

Cathode copper of 102 per cent. conductivity was used, and the ingredients added were the purest obtainable.

1. THE EFFECT OF PURE BISMUTH ON COPPER.

Micrograph No. 11 Q represents a highly-magnified portion of copper containing 0.05 per cent. bismuth; no oxygen is present. This structure is typical of copper containing from 0.5 to 0.05 per cent. bismuth, the difference being that the *loci* of segregation are fewer and further apart as the percentage of bismuth decreases.

It will be noticed that the material wedging apart the crystals of copper is of two kinds, one being an extremely light shade of greenish-blue in colour, and structureless; the other is also structureless, but it is a decided *blue* in colour and differs from the former constituent in two other ways, viz.:—

* *Metallographist*, vol. vi. 1903.

1. In its general form, occurring mostly as rounded areas—apparently globules in section—while the greenish-blue constituent occurs more often in river-like streaks, apparently plate-like envelopes in section.

2. It is unaffected by the action of hydrofluoric acid, whereas the light constituent is stained black.

The light constituent is metallic bismuth, probably of great purity. The darker constituent may be due to an impurity in the cathode copper; it may possibly be cuprous sulphide.* It is not cuprous oxide, since cuprous oxide is stained black by immersion in hydrofluoric acid.

Micrograph No. 12 Q shows the highly magnified portion of one of these sectional envelopes of bismuth separating crystals of copper from one another. This sample contained 0.10 per cent. bismuth. This particular section shows much more of the darker constituent† than occurs in an average area of the specimen. The presence of bismuth seems to have induced it to occur in similar elongated forms, tandem-wise with the bismuth films.

This experiment was performed in an exactly similar way to that described under No. 11 Q.

2. THE EFFECT OF BISMUTH ON COPPER IN THE PRESENCE OF OXYGEN.

Micrograph No. 13 Q shows the highly-magnified portion of a specimen of copper containing 0.5 per cent. bismuth and 0.082 per cent. oxygen.

Micrograph No. 14 Q shows, under similar magnification, a portion of a specimen of copper containing 0.5 per cent. bismuth and 0.11 per cent. oxygen.

* In order to gain further knowledge of the identity of this substance, the author has experimented with some of the cathode copper as used in all these experiments, *i.e.* the copper was melted under charcoal and allowed to cool out with the furnace, no bismuth being added and oxygen being rigidly excluded. A specimen sawn off from the button when cold was polished and examined under the microscope before etching. The darker constituent, as described under *Micrographs No. 11 Q* and *No. 12 Q*, was plainly discernible in isolated, widely-distant areas of a similar blue colour, this colour being unaffected by etching in hydrofluoric acid. This is strong confirmation of the author's belief that the substance is cuprous sulphide, and analyses are now being carried out to determine quantitatively the amount of sulphur present in the copper.

† Cuprous sulphide.

In specimen No. 13 Q there may be seen three constituents in addition to the metallic copper matrix:—

1. Globules of bismuth; light colour. Structureless.
2. "Oxidules" (cuprous oxide); light - blue colour. Structureless.
3. Irregularly-shaped particles of a constituent slaty-blue in colour, occurring contiguous to the "oxidules," and having a composite structure.

In specimen No. 14 Q the two latter constituents only are in evidence, the metallic bismuth globules being absent.

These two micrographs are of typical areas from the surfaces of the two specimens, but it must be understood that such areas are very widely distant from one another.

It would seem as if there was not enough oxygen present in No. 13 Q to convert all the bismuth present to the oxidised form, whereas in No. 14 Q the oxygen present is in just sufficient quantity to effect this result.

The most marked difference between the microstructures of these specimens and those of copper containing bismuth and no oxygen (see Micrographs No. 11 Q, 12 Q, and 15 Q) is that the bismuth no longer exists as elongated plates between the copper crystals, but either as isolated globules of metallic bismuth, or as irregularly-shaped particles of an oxidised form of bismuth (constituent 3, above).

The composite character of this constituent has been confirmed by adding pure bismuth oxide (Bi_2O_3) to pure molten copper and treating in the same way as the specimens 13 Q and 14 Q, *i.e.* allowing to cool slowly at the mouth of the hot furnace, in a crucible and under a covering of the neutral sodium-silicate slag under which the copper had been melted.

The general appearance of this constituent is as follows:— In general outlines it resembles the phosphide eutectic so commonly occurring in cast iron. It consists of a slaty-blue matrix, relieved with streaks or uniformly-scattered particles of what is apparently pure copper. It may be an eutectic of copper and bismuth oxide, or it may be bismuth oxide holding a form of "moss-copper" analogous to that which separates out from low-grade mattes. In the latter case it must be

assumed that the copper was soluble in bismuth oxide at high temperatures, but was thrown out of solution as the alloy cooled. Further research is necessary to make clear the identity of this constituent. It is a notable fact that copper containing 4.5 per cent. bismuth as Bi_2O_3 is noticeably more malleable than copper containing 0.5 per cent. bismuth in the metallic form, and these experiments seem to show that it is owing to its existence in commercial copper in this oxidised form, where it occurs as isolated particles rather than as brittle metallic films, that bismuth is less harmful than it would be if oxygen were not present.

3. THE EFFECT OF BISMUTH ON COPPER IN THE PRESENCE OF ARSENIC.

Much has been said of the beneficial effect of arsenic when added to copper containing bismuth, and several theories have been advanced to explain it. The author has no hesitation in disputing any theory which attributes this effect to the superior solvent power of a compound of copper and arsenic.

The cause,* possibly, lies in the "quick-setting" properties of arsenical copper. Pure copper sets or solidifies more slowly than copper containing arsenic, and so any bismuth present will be given more time to separate out and find its way to the crystal-boundaries.

If this "range of solidification" is shortened—and arsenic assuredly does shorten it—then the bismuth may be arrested in the form of small particles migrating towards the boundaries. Hence less bismuth will appear at the boundaries, segregation will be less marked, and the bismuth which occurs scattered in the form of "arrested" particles will be very much less harmful. The copper will have better hot and cold-working properties.

Micrograph No. 15 Q shows the structure of oxygen-free copper containing 0.5 per cent. bismuth (an amount at least ten times higher than may be found in wrought copper) and 0.24 per cent. arsenic, slowly cooled.

* [The theory advanced in this and the following paragraph was withdrawn by Mr. Johnson during the reading of the paper.—ED.]

The light greenish-blue constituent separating the crystals from one another is metallic bismuth, and the numerous minute specks which occur, fringing, as it were, each boundary on either side, may be particles of metallic bismuth, arrested by the "quick-setting" action of the arsenic-rich envelopes.

These specks do not occur in arsenic-free copper containing the same quantity of bismuth; whereas with an increase of arsenic (say 1 per cent.), and bismuth remaining constant, they are much more numerous, occurring with frequency in the very "cores" of the crystals themselves.

Occurring side by side with the metallic bismuth plates are to be seen occasional smaller areas of the darker blue β constituent (Cu_3As of the copper-arsenic series),* which apparently has no solvent action whatever for bismuth. The latter may be readily distinguished from the former by reason of its greater pallor, but may be rendered much more distinct for purposes of reproduction by etching in hydrofluoric acid, which blackens the bismuth constituent, the arsenic constituent retaining its original colour. See Micrograph No. 16 Q.

All these three specimens were furnace-cooled, the conditions being exactly the same as in the case of Nos. 11 Q and 12 Q.

All the micrographic work was done on the Zeiss micrographic apparatus in the Metallurgical Department of the University of Birmingham, and the results here recorded are to be regarded as supplementary to, and in a measure explanatory of, the main body of the research. They are not intended to represent a complete microscopic study of the subject.

CONCLUSIONS.

It has been clearly brought out by the foregoing experiments that all three of the impurities—silver, bismuth, and aluminium—have very marked effects on the mechanical properties of arsenical copper, effects which are more apparent in the tests of the hot-rolled than in those of the cold-worked and annealed material.

* "The Properties and Constitution of the Copper-Arsenic Alloys," *Journal of the Institute of Metals*, vol. iii, No. 1, 1910.

The effect of silver in the proportions usually found in commercial "tough" arsenical copper may be considered as beneficial on the whole as regards mechanical properties, and negligible as regards hot-working properties.

The effect of bismuth on the mechanical properties of "tough" arsenical copper which has been rolled is not serious up to 0.10 per cent.; but no commercial arsenical copper could be regarded as fit for working at a red-heat which contained so much bismuth. With 0.02 per cent., although the hot-working properties would be noticeably worse than if no bismuth were present, the copper would not be ruined. Any crude copper containing over 0.01 per cent. bismuth should be regarded with suspicion, since the copper might contain traces of other impurities—*e.g.* nickel—which, while intensifying the injurious effect of bismuth, would hinder the corrective action of arsenic.

(The influence of bismuth on the mechanical properties of arsenical copper at high temperatures has not been investigated in this research.)

Arsenic and oxygen both aid in improving the mechanical properties of copper containing bismuth. In addition to the function exercised by cuprous oxide in guarding molten copper from the inroads of reducing-gases and their subsequent devastating influence, there may be ascribed thereto also the function of protecting the solid metal from the inter-crystalline weakness engendered by metallic bismuth.

The effect of aluminium in arsenical copper is to destroy its hot-working properties and to impair its physical properties in the cast, and its mechanical properties in the rolled condition.

In but few inadequate words can the author express his sincere thanks to the following gentlemen:—Professor T. Turner, for much valuable advice and encouragement; Professor J. O. Arnold, for invaluable aid in carrying out the alternating-stress tests; Professor S. M. Dixon and Mr. F. H. Hummell (Civil Engineering Department, University of Birmingham), for carrying out the tensile tests; Mr. O. F. Hudson, for much personal aid; and Mr. T. K. Browne (Professor Turner's assistant) for re-drawing the diagrams.

DISCUSSION.

Mr. JOHNSON, in introducing his paper, drew attention to the importance of Tables VII., A to B, as embodying the main features of the research. He pointed out that a greater latitude might be observed in the matter of bismuth content where the copper had to be hot-rolled into sheet than where it had to be hot-rolled into rod or wire. The defects in the former case manifested themselves mainly in ragged edges which could readily be sheared off, and the most serious consequence of the presence of the impurity was a possible increase in the quantity of scrap. In the latter case, however, the defects were not removable, a length of rod or wire showing slight superficial fissures from end to end. That undesirable state of things might render necessary the scrapping of the whole of the material, or at the best would be a source of considerable trouble in the cold drawing. He wished to emphasise the usefulness of the microscope in enabling the metallographer to detect at a glance whether a specimen of copper had been refined and cast as "tough-pitch" copper, or whether it had been deoxidised prior to casting (*e.g.* by means of phosphorus). In the former case, cuprous oxide would show clearly as "oxidules"; in the latter case, no "oxidules" should be discernible.

In conclusion, he wished to advance a theory to explain how it was that "tough-pitch" copper should show a level surface. He drew on the blackboard diagrams representing ingots of copper in section: (1) "Set" copper (showing a concave surface), representing copper with excess of cuprous oxide, before poling; (2) "tough-pitch" copper (showing a level surface), representing copper which had been "poled" up to pitch; (3) "overpitch" copper (showing a convex surface), representing copper which had been "poled" for too long a period. He described the fractures of these as follows:—In case (1), a "dry" fracture, free from vesicular cavities; in case (2), a silky fracture, but also tiny vesicular cavities of uniform size and distribution. The bright unoxidised

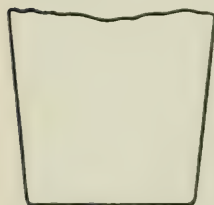


FIG. 1.
"Set" Copper.

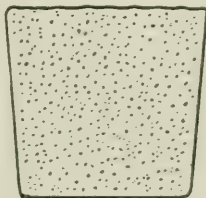


FIG. 2.
"Tough-pitch" Copper.

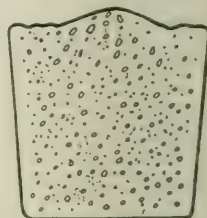


FIG. 3.
"Overpitch" Copper.

character of these minute cavities indicated that the gases which had filled them were of a reducing nature. In case (3), a silky fracture, but more numerous cavities, some of them larger than others, the larger ones occurring more at the top of the ingot.

He thought that the bubbles of gas which caused these cavities were released at the moment of solidification, and by reason of their natural buoyancy exerted an upthrust which tended to oppose the effect of shrinkage, viz. "piping." In the case of "underpoled" copper they were insufficient to oppose this effect; in the case of "tough-pitch" copper they were just sufficient to keep the surface from sinking, and thus the metal maintained a level surface from the molten to the completely solid state. In the case of "overpoled" copper the gases were released in such a quantity as to not only neutralise the effect of shrinkage, but to elevate the surface of the ingot, or even to throw some of the semi-molten copper out of the mould. It must be remembered that in "tough-pitch" copper these cavities were too minute to affect the forging properties, and moreover their presence would be rendered innocuous by the effects of reheating and hot-forging.

Mr. J. H. HEAP (London) said that as one interested in the manufacture of arsenic, that paper gave him unusual pleasure. He said "unusual" advisedly, because he was accustomed to hear arsenic so regularly abused in metallurgical discussions that it was quite a rare treat to listen to such papers as that by Messrs. Bengough and Hudson given at a previous meeting, and the present paper, in which the value of arsenic was recognised, and the metal itself regarded with proper respect. He felt sure that as investigation proceeded the merits of arsenic would be further proved; and it only needed a little courage to demonstrate, as had been done in the case of human beings, that gradually increasing doses not only ceased to show the early effects, which were not so favourable, but brought about beneficial results. Seriously speaking, he would like to ask the author his reason for not proceeding, as he rather thought he had not proceeded, with what probably he would admit was the ideal way of making tests of that character. He gathered an impression from the early part of the paper that he had not added arsenic in the form of metallic arsenic. There were certainly some remarks later which appeared to contradict that. Perhaps he would be good enough to state clearly what he had done. As he (Mr. Heap) understood it, Mr. Johnson took pure electrolytic copper and added to it impure copper. That impure copper contained varying quantities of arsenic, the percentage of which he did not know beforehand. He made mechanical tests of that mixture, and then analysed the mixture to see what percentage of arsenic and impurities was there. That assuredly was not the ideal way to obtain tabular results which were likely to be the most useful. It was evidently the best way to take pure electrolytic copper and add those elements, the effects of which he proposed to study one by one.

Mr. JOHNSON said that that was exactly what he did.

Mr. HEAP, continuing, said he wished the author to state that quite clearly, because if they referred to a statement on page 175 it did not

seem to agree with that. There the author said: "As regards the form in which the metal entered the crucible, the copper was introduced as clean cathode copper of 99.90 per cent. purity. Arsenic was added in the form of an alloy of cathode copper and metallic arsenic of 99 per cent. purity." Did the author mean by that that an alloy was prepared specially beforehand to contain a certain percentage of arsenic?

Mr. JOHNSON replied affirmatively.

Mr. HEAP said that made it clear, but he had been rather strengthened in the belief that arsenic was not combined in any fixed proportions and had not been predetermined in regard to those proportions, by one or two tables in which the author said that arsenic was present in practically the same percentage, and in which nevertheless it appeared that those percentages differed sufficiently to make a difference in the result. For instance, in certain of the tables it would be seen that there were marked differences in the proportion of arsenic. In Series E the proportion of arsenic differed sufficiently in percentage to affect the results. Yet the author spoke of the arsenic as being in approximately constant proportions. Perhaps the author would refer more fully to that point. It was quite evident that in the paper the author had emphasised that two elements were essential in making the best "tough-pitch" copper. Personally, he should prefer to speak of one as essential and the other as beneficial. That seemed to him the better way. Oxygen was essential, and arsenic was beneficial. The other elements were impurities which did more or less harm but were corrected by the arsenic. He would rather like to ask the author whether he did not think that by the addition of arsenious oxide, which he noticed was mentioned in one case, the beneficial effects of arsenic would not be obtained in the highest degree. He would not suggest using arsenious oxide in the form of powder. There was a special form, commonly called "lump-white" arsenic, which seemed to him likely to give the beneficial results in a very marked degree. He did not know whether the author had considered exactly what happened with the oxygen contained in the arsenious oxide, which was an interesting question. But he thought it ought to be considered in connection with his method of varying the quantities of oxygen in the copper. It seemed to him that in varying the quantities of oxygen in the copper by introducing oxygen in the atmosphere, there was another complication introduced which had been alluded to, namely, the difficulties arising in connection with nitrogen being occluded in the copper. If the oxygen could be introduced in some other form it would not only simplify the method of studying the effects of the respective elements, but it would avoid the introduction of other undesirable elements. It was obviously necessary in investigations of that kind only to introduce those factors that the investigator was considering in his arguments. He considered the paper was exceedingly interesting, and must have meant a great amount of tedious, although most useful, work on the part of the author.

Professor TURNER, M.Sc., Honorary Treasurer, said he would like in the first place to express his appreciation of the character of the paper which Mr. Johnson had brought before them. It was one of those combinations of practice with theory of which they had heard a good deal in connection with the present meeting, because those experiments were all conducted in the works, as far as possible under works conditions, by a man who was in the works, and had been in the works for some years, and who was a copper man. He thought the remarks of the previous speaker would go some way at all events to help them to appreciate the difficulty attending investigation of that kind. He was tempted to take an illustration from iron, although that was a non-ferrous association. There was a time in connection with the investigations into the properties of iron that the chemists argued from the effect of an element upon the properties of mild steel as to what the influence would be upon cast iron. The result was that entirely erroneous views were held. As an example he need only mention silicon, which at one time was thought to be detrimental in all proportions and to be avoided as far as possible. In the case of copper, if they were considering electrolytic copper on the one hand or considering wrought copper on the other, they were dealing with materials as different in their composition, and in regard to mechanical and other properties which were required, as wrought iron and cast iron. Mr. Johnson, therefore, had the difficulty of starting with material purposely impure, and he had to maintain those impurities of the arsenical copper as uniform as possible. To keep the pitch of copper during experiments of that kind, when they were working only on a small scale, was a matter of difficulty which only those who had tried to do it could appreciate. Copper would go past the pitch or was just under the pitch as the case might be, in a very few moments. Mr. Johnson had given particulars as to the method of casting his bar. Any one who had to do similar experiments would find the information given as to the method of casting of very great use in the future, from the practical point of view. What he told them as to the effects of bismuth was interesting and important. Wrought arsenical copper might contain an amount of bismuth sufficient to make pure copper quite unsuitable for rolling, and the difference between 0.05 and 0.02 per cent. of bismuth would mean, of course, everything, in regard to copper. In reference to silver and aluminium, it would be seen that in small proportions they had no ill effect apparently, but a good effect upon wrought copper. Some one might ask, "Why do you think of adding silver or aluminium to copper, seeing that these are expensive materials?" Very often in commercial copper, not electrolytic, there were small quantities of silver present which it might not pay to remove. He had been interested in the work as an outsider and a spectator, and he could testify the very great care Mr. Johnson had shown in the work, and the amount of energy called for by those experiments.

Professor H. C. H. CARPENTER, M.A., Vice-President, said it seemed to him that the paper was exactly the type most wanted in the Institute,

because it represented a combination of practical and scientific knowledge, and described the result of work carried out scientifically under works conditions. From this standpoint the work done would stand criticism very well indeed. He was very glad the author had withdrawn his theory on page 203, because he thought that in that form the theory was clearly incorrect. At the same time he thought he knew what the author intended to convey, and he thought he was right, although the matter had been not quite correctly stated. On page 200, he had been particularly interested in what he considered the most valuable part of the paper from the scientific point of view. That was in regard to the action of bismuth on "tough-pitch" copper, and the extent to which it was associated with oxygen. First of all, taking the action of bismuth on pure copper, there was the question of that dark constituent in copper which contained no oxygen, and which Mr. Johnson considered was cuprous sulphide. He thought that was very likely, but he did not think it was quite proved yet. But it seemed as if the point could be settled in one of two ways. One way would be by the use of some reagent which would set free sulphuretted hydrogen, and allow it to act on sensitive paper in the same way that sulpho films in iron and steel were investigated. The second way would be by adding increasing amounts of cuprous sulphide to copper and observing their effect on its structure. Coming next to page 164, associated with photograph 13, he did not think it was quite clear as it stood. It was suggested by the author that there were three structural constituents. He (Professor Carpenter) had not been able to detect more than two. He thought it would greatly increase the value of the paper if the author could introduce explanations of the different constituents, with the names of structural constituents in the margin. That would throw a good deal of light on the photographs 13 and 14. He thought the general theory that the author gave in the paper was quite probably correct, apart from the one he had withdrawn. He said that, because the author had asked for expressions of opinion about the theory. Mr. Johnson had been kind enough to send him three ingots representing arsenical copper in those three forms. As far as he could see, the explanation that Mr. Johnson had advanced was quite likely to be correct. He felt sure the explanation was connected with the liberation of gases at the moment of solidification in the copper.

Mr. G. D. BENGOUGH, M.A. (Liverpool), said he was sorry to say he had not had time to go into the paper very carefully. He would like to ask Mr. Johnson as to the analysis of the oxygen in the copper. He noticed that Mr. Johnson estimated his oxygen by loss in weight. He rather wondered why he adopted that method instead of weighing the water directly. He was rather sceptical about the analysis of oxygen in copper by that method, especially if they had to deal with 20 grammes of material. Then, he would like to know more as to his method of taking samples. Did it mean that he hammered the metal down into strip, and afterwards cut it up, without taking samples by drilling.

Sampling for oxygen analysis was not very satisfactory, because there was always a liability to get slight surface oxidation, especially when drilling. Also, in regard to the effect of nitric acid; did not that dissolve out some oxide on the surface. It appeared that he treated the sample with nitric acid before subjecting it to the reducing action. There was also a point on page 187 in which Mr. Johnson said: "There seems to be no advantage in adding arsenic as metallic arsenic, in which form it was added to all the above bars except V¹, to which it was added in the form of arsenious oxide." In an old paper read before the Society of Chemical Industry, Mr. Platten took part in the discussion, and then stated that there was considerable difference in the effect on copper if arsenic was added in the metallic form rather than in the oxide form. He would like to know whether Mr. Johnson would state definitely that he found no difference at all. He presumed his idea was that arsenious oxide was reduced by the copper, and that therefore they arrived at the same sort of thing, whichever way they added it. There was another point with regard to the estimation of oxygen. Sir Gerard Muntz had asked him if he knew whether there was any way of estimating the amount of oxygen in brass. Personally, he was obliged to give a non-committal reply, so he had much pleasure in passing that question on to Mr. Johnson. With regard to the last page, which was page 205, he would like to know whether the author had made any estimations of the amount of reducing gases held in copper. He thought it would be very interesting indeed to find out what was the composition of those reducing gases, and whether they were really got into solution in any of those poling processes, and whether they could be kept in solution and so prevented from forming blowholes in the way described by Mr. Johnson on the board. He had been most interested in the paper, and when he had made a rather more careful study he would no doubt come across a great many more points of interest which would enable him to contribute something to the *Journal* in writing in rather a more systematic and detailed form than was now possible.

The PRESIDENT said they had had some very interesting comments from the scientific side, but they had a representative of one of the greatest firms in the country handling copper, namely, the Broughton Copper Company, and if there was a company which knew more about copper than anybody else that was the company. He had no doubt their representative could make some valuable contributions.

Mr. J. B. MERCER (Knutsford) said he was connected with the Broughton Copper Company, which had been interested in the use of copper, but his interests were of a commercial kind, and he was not an expert. He must therefore beg to be excused.

The PRESIDENT regretted that Mr. Sumner, who was a member of the Corrosion Committee, was not present. Unfortunately, he was unable to attend, but they hoped to receive a contribution from him in the future.

Mr. C. H. WILSON, Member of Council, remarked that he had very little to say, though he wished to express his very high appreciation of the value of the paper. His experience had not been so much with copper as with silver-copper alloys. With regard to the point raised as to the liberation of gases at the moment of solidification, he had had frequent experience in cases where there had been difficulty with some of their castings. What the paper suggested—namely, the liberation of gases at the moment of solidification—appeared to offer the explanation. With regard to the diagram shown on the blackboard, he had found larger castings than those referred to acting peculiarly. The castings were made in closed chilled moulds, and it was found that when the ingots came to be rolled into sheets they were unsound down the centre, whilst sound at the sides, where the chilling took place, almost immediately on pouring into the mould. Although there was no sign of anything wrong on the surface, yet in the centre there had been very considerable defects very much of the kind depicted on the blackboard.

Mr. E. L. RHEAD, M.Sc. Tech. (Manchester), said that the subject that had been undertaken by Mr. Johnson was of such magnitude as made it scarcely possible to deal with it adequately except by prolonged study of the paper. One or two points had been adequately dealt with by previous speakers, notably the analytical questions, as well as one in connection with the micrographs. He would like to add to the remarks of Professor Carpenter that he was also not quite clear upon the description of No. 4A, in which two of the three mentioned constituents were said to be present. He was afraid he could not follow the description, because he was not quite clear as to which of those two constituents were intended to be understood as being present. Otherwise, the micrograph and the effects produced were quite clear. With Dr. Carpenter, he was quite glad to know that Mr. Johnson withdrew the question of "quick setting." He intended to refer to that, and to ask the author whether the "quick setting" referred to was due to the rapid liberation and loss of heat in some way or other, or whether it was due to the cooling down below the actual melting point, and the sudden solidification of the copper due to some change which was not necessarily entirely loss of heat—some such solidification as occurred, for example, with a super-saturated solution. He would like also to ask Mr. Johnson whether he had considered the effects of arsenic and antimony in the same connection as arsenic and bismuth. He thought it was an important point that was certainly not clear whether the introduction of arsenic also neutralised the effects of antimony which was usually supposed to have harmful effects not much less than those of bismuth. He believed that was an undecided point, whether it was by itself as harmful in copper as it was generally supposed to be. One other point he thought it worth while to raise, and that was in connection with the remarks on page 170, in which reference was made in the upper part of the page to the fact that bismuth separates or "occurs as minute globules of oxide isolated from each other by similar globules of cuprous oxide as existed in the

copper cuprous oxide eutectic." The thought occurred to him in connection with the fact that oxide of copper promoted the separation of bismuth in the form of globules, that it might possibly be the result of a similar effect to that produced by the introduction of ammonium chloride and certain other salts into solutions containing matter in the colloid form, and whether the action of the added matter (cuprous oxide) was actually one of causing minute particles of the colloid to run together and so produce particles of distinct size. He thought that was a phase in connection with the effect of impurities on metals which was not at present touched, and it was one which, when followed out, would yield important results. At present they knew practically nothing of the nature of the particles of substances dissolved in metals at high temperatures. It was not at all unlikely, and he thought they might even say that perhaps the high temperature had some effect in producing the colloid form or something analogous to it. He would like to join with the previous speakers in expressing his entire appreciation of the immense amount of work Mr. Johnson had done, and the very valuable character of the work. It was, as had been already said, exactly the work that should be done, namely, experimental work by chemists and metallurgists actually engaged in works-practice.

Mr. W. H. JOHNSON, Vice-President, said he wished to add his testimony to the great value of the paper, which was just the kind that manufacturers desired to have. It gave results of careful scientific analysis in the works, and under works conditions, and thereby added appreciably to their store of scientific knowledge. While they appreciated all kinds of knowledge, what they most needed was to get papers of that kind where the practical element was brought to bear on the subject immediately dealt with, and to have scientific criticism of those who made it their sole object to study all those difficult questions. The criticism of the scientists on that paper was of immense value, and greatly advanced them in the application of results to their own manufactures.

The PRESIDENT said there was another gentleman present, Mr. Hopkins, who, if he chose, could greatly enlighten them from his stores of practical experience. Mr. Hopkins knew all there was to be known on the subject of copper under works conditions. He hoped he would not hide his light under a bushel.

Mr. HOPKINS said he regretted to be unable to take part in the discussion.

The PRESIDENT said he greatly regretted that, but they hoped to hear from Mr. Hopkins in future.

Sir WILLIAM WHITE, K.C.B., F.R.S., past-President, said he wished particularly to deal with what sounded almost like an apology from Mr.

Johnson in his allusion to the work of the late Professor Roberts-Austen. It was his fortune to be associated with Sir William Roberts-Austen for some years, in work for the Alloys Research Committee of the Institution of Mechanical Engineers, of which Committee the speaker was then and still continued to be the Chairman. Therefore he could speak the sentiments of his dead friend, and could assure Mr. Johnson that no such feeling as he had expressed was necessary. Professor Roberts-Austen would have been the first to regret that his work had to be chiefly carried out under conditions not comparable with actual works-practice. The work done by and for the Alloys Research Committee was purely laboratory work, the results of which were intended, if successful, to suggest, and, indeed, succeeded in suggesting to those engaged in works-practice, methods of procedure superior to those they had before employed. Several speakers had already remarked that the best results affecting practice could only be obtained by research conducted in the works themselves. There again Sir William Roberts-Austen would have been the first to admit that statement to be absolutely true. In the quiet of his laboratory, the scientific investigator, working under what the first speaker described as ideal conditions, and dealing with impurities or alloys introduced in a manner which admitted of no doubt as to character and quantities, would obtain exact results and so furnish suggestions for improvement in works-practice. But it was impossible, nor was it desirable, that such laboratory work should attempt to exactly imitate or embody all the varied conditions of ordinary work. That kind of research, in his judgment, was best attempted in the works themselves, and in that respect British metal-makers may have somewhat lagged behind Germany and other countries in which there had been a greater amount of research work done in works and in factories. Having been for a number of years in charge, and having supervision of, materials manufactured for the Admiralty for the purposes of shipbuilding, he might fairly claim to be familiar with the conditions of works until comparatively recent times. He knew also some of the largest works in Germany; and he was of opinion that on the whole this country in that particular had lagged behind Germany, although the most recent progress had put us in a better relative position. It was that latest advance to which Mr. Johnson referred, which in his (the speaker's) opinion was one of the greatest factors in modern manufacture. He was well aware that in the metal trades, including the non-ferrous metal manufacturers, methods of scientific research were now being widely applied, and producing beneficial results. He was not competent to speak so fully on this paper as many speakers had been, but knowing something about copper as applied for naval purposes, he could not help thinking that this paper would be of immense value, bringing together as it did much information and giving many valuable references. They all recognised the significance of that paper. It had proved how, under fully trained thought and inquiry, workers might take up and apply their own intelligence and their own methods to procure more exact results. In conclusion, he would ask whether any experiments on a scale representing

the operations of practice had been made in casting copper ingots under pressure. Perhaps Mr. Johnson would kindly answer that question.

The PRESIDENT said that he wished to make a remark or two himself, especially as he had failed to induce his friends Messrs. Mercer and Hopkins to speak from the practical side. A point that struck him was that in the author's test bars the contents of arsenic and oxygen were very erratic, and it was hardly fair to compare bars where the proportions of arsenic and oxygen were so dissimilar, because they must not lose sight of the fact that both the arsenic and the oxygen had a large effect upon copper, and that the proportions of arsenic to oxygen had a very large effect on the ultimate results. Therefore, to make their experiments satisfactory, they must have a constant proportion in either oxygen or arsenic, before they could arrive at any conclusion on the effect that either would have upon the copper. That was a point he would like future investigators to devote their attention to. Then, to come back to Professor Turner's remarks, he referred to the fact that electrolytic copper and ordinary copper, "tough copper," were different materials. With all deference to the Professor, he must disagree that they were different materials. They were the same materials, only in the tough copper they had the copper spoilt by the addition of different materials. With regard to the question of using metallic arsenic or arsenious oxide for the purpose of adding arsenic to copper, speaking from some experience, he would say that the results obtained were very varied. The effect of adding metallic arsenic and the effect of adding arsenious oxide were quite different. They could obtain ultimately the same results from both, but they had to deal with totally different alloys, and the same proportions did not fit into both cases. They were totally distinct processes. Metallic arsenic was the best; if they used arsenious oxide they had an element which they did not want. They had to get rid of the oxygen, and they had better add arsenic in metallic form. As to the point referred to by Mr. Johnson, as to what happened in the solidification of the bar, his own experience led him to believe that that action of the gas was an absolute fact. With regard to the effect following the oxidation of copper, he hoped by-and-by to place something before the Institute on that subject, but at present he was not ready. But as to the fact that there was a liberation of gases at the time of solidification there was no doubt about that. A point had been raised by Sir William White with regard to casting under pressure. A gentleman who could have told them all about that was not present, and his representatives would not act for him, but there were people casting under pressure very successfully. From his own point of view, he (the President) should consider that casting copper under pressure ought not to be necessary, and if the metallurgists knew their business there should be no reason for getting out the gases by mechanical means. That was quite an unnecessary aid to metallurgical practice. They ought not to have to get out their gases at all, because in successful work the gases should not be there when the metal was cast.

Mr. F. JOHNSON, in reply, said that he must first express his very sincere thanks for the reception of his paper, and he could only trust that it had been of use to those interested in the copper trade. In regard to most of the questions raised, it would be better for him, owing to the shortness of time, to reply to them in writing. Some reference had been made to the effect of arsenious oxide in copper as compared with metallic arsenic, and that question had also been referred to by Mr. Heap.

Mr. Bengough had referred to Mr. Platten's remarks made at a meeting of the Society of Chemical Industry. He (Mr. Johnson) had had the pleasure of attending that meeting, and he had understood that Mr. Platten's experience was as follows. When manufacturing arsenical copper in the refinery, if arsenious oxide were added to the molten metal, the final product of that charge (*e.g.* tubes) gave lower values in tensile strength than similar material obtained from a charge to which the arsenic had been added in the metallic form. The percentage of arsenic was the same in each case. No details were given as to other conditions, *viz.* percentage of oxygen, &c. He (Mr. Johnson) did not think that the difference in tensile strength could be very much—possibly a quarter or half a ton per square inch.

By conducting experiments in crucibles one could closely follow the method of procedure adopted in a refinery, with the advantage of greater exactness when care was exercised.

By taking equal quantities of electrolytic copper, and adding in one case arsenious oxide, and in the other case metallic arsenic and copper oxide, so that the molten charges were identical in chemical composition, one could experiment with the safe knowledge that the only variable factor was that arsenic and oxygen had been introduced in one case in the form of a compound (As_2O_3), and in the other case had been introduced separately. He (Mr. Johnson) thought that in the molten state there was, theoretically, no difference at all.

Now supposing that the percentage of arsenic were 0.36 per cent. in each case, then the oxygen (according to the formula As_2O_3) would be 0.12 per cent., but this is sufficient to cause the metal to be "under-pitch." If "poling" were resorted to in each case to the same extent, in order to reduce the proportion of oxygen and bring the contents of the crucibles to the "tough-pitch" condition, where the resulting ingots would exhibit level surfaces and their analyses would show practically equal quantities of oxygen, then those ingots should, after identical treatment in rolling, give identical results in mechanical tests. He must express his very hearty thanks to Professor Turner and Professor Carpenter for their appreciation of the paper; he greatly valued Professor Carpenter's support of his theory with regard to the effect of reducing gases on the surface of the copper, and to Sir William White his thanks were also very largely due in removing the sense of temerity and almost awe which he felt in comparing his work with that of so famous a scientist as Sir W. Roberts-Austen. With regard to Sir William White's question, which Sir Gerard Muntz had already answered, as to the employment of pressure on molten copper castings, that was a matter very much in

debate at the present time. He might say that two firms in Birmingham and one firm in Manchester—the Broughton Copper Company—had employed those methods, but Sir Gerard Muntz did not agree that they were necessary, considering that the gases should be got out without mechanical means. Perhaps it would be better for him not to follow that question any further, and he would content himself with replying to further remarks and questions in writing.

COMMUNICATIONS.

Mr. JOHNSON wrote, in further reply to some of the points that had been raised at Glasgow during the discussion of his paper.

Replying to Mr. Heap's questions, he wished to state that the cupro-arsenic alloy used for introducing arsenic into the copper had the following composition:—

	Per Cent.
Copper	83.06
Arsenic	16.90

and that the same quantity was used in every experiment. Little difficulty was experienced in casting bars with a constant proportion of arsenic. Mr. Heap pointed out that the final percentages of arsenic did vary, and thought that those variations might affect the results. He (Mr. Johnson) had dealt with this point in the paper (page 172), and had shown that a variation of 0.70 per cent. arsenic in the case of the experiments of Messrs. Bengough and Hill had made no difference in the results of their tests. In some of his (the author's) experiments, as was also explained, recasting was necessary where an ingot had not been poured at the proper stage of "pitch." It must not be forgotten that copper was an expensive metal with which to experiment, hence the necessity for remelting and recasting defective ingots. The oxidising elimination of part of the arsenic to varying extents during the process of remelting accounted for the varying percentages.

The greatest variation (in bars X and Z) need not be considered, because it could not affect the main conclusions regarding the influence of aluminium as set forth in the last paragraph of the paper.

In the case of the "tough-pitch" bars whose results were plotted in the curves, the greatest variation of arsenic in those containing silver was 0.11 per cent. and in those containing bismuth was 0.06 per cent. Such variations, Mr. Heap might rest assured, were negligible, as all those practically engaged in the copper trade would affirm.

Mr. Heap objected to the use of atmospheric air as a means of introducing oxygen, thinking that nitrogen might be taken up by the copper. Mr. Heap's fears were groundless, no one having yet succeeded in finding nitrogen in copper. Moreover, it had been proved that molten copper would not absorb nitrogen even at temperatures above those reached in practice. Finally, if molten copper did absorb nitrogen, the author

would feel strengthened in his preference for employing the aid of atmospheric air, since his endeavour had been throughout to produce ingots under the same conditions as those obtaining in works-practice.

In acknowledging Professor Turner's remarks, he would like again to express his indebtedness to him, for although he said that he had been only a spectator, from no one had he (Mr. Johnson) received greater encouragement or more useful advice.

He would add that, so far as the effect of aluminium was concerned, it was of distinct practical advantage to know its effect upon arsenical copper, because of possible attempts to produce arsenical copper from crucibles, in which attempts aluminium might be considered as a possible deoxidising agent. Moreover, the experiments might serve as a warning to manufacturers to keep out of their arsenical furnace-charges all scrap which may contain aluminium, *e.g.* aluminium-bronze wire, the introduction of which was by no means a remote possibility. He was glad that Professor Turner had emphasised the difficulties attending the experiments in preparing "tough-pitch ingots"; he (the author) thought it really remarkable with what rapidity a few pounds of molten copper would go under or over the "pitch."

Professor Carpenter had suggested a synthetical preparation of copper and cuprous sulphide in order to confirm the identity of the constituent which occurred alongside the bismuth (see micros. No. 11 Q and 12 Q).

That had been done, and the constituent which appeared was identical with that under consideration in—

- (1) Colour.
- (2) Appearance (*i.e.* mainly as rounded areas).
- (3) Maintenance of colour after etching in hydrofluoric acid.

This constituent (Cu_2S) probably formed a copper-cuprous sulphide eutectic. The writer intended further to confirm its identity by some such method as that employed by Stead,* and alluded to by Professor Carpenter. The cathode copper used gave, on analysis, 0.009 per cent. sulphur.†

Professor Carpenter asked for the introduction of lines indicating the position of the constituents in micrographs 13 Q and 14 Q. The author endeavoured to have this done before the paper was published, but the printers did not find it practicable. In No. 13 Q, the light-coloured, rounded areas in the top half of the micrograph represented metallic bismuth. The dark constituents shown in the lower half represented cuprous-oxide ("oxidules") fringed with the slaty-blue, composite bismuth constituent (No. 3, see p. 202). In No. 14 Q, the cuprous-oxide areas were shown as structureless "oxidules" (half-tone) fringed with the composite bismuth constituent. In No. 16 Q, the light-coloured constituent was Cu_3As , the black constituent being metallic bismuth (stained black by etching with hydrofluoric acid).

* *Journal Staffordshire Iron and Steel Institute*, 1908.

† See also discussion on "Copper and Copper Alloys" in this *Journal*, vol. i. No. 1, p. 80, Gowland.

In reply to Mr. Bengough, the author would refer him to a paper read by Archbutt,* in which he stated that the method of determining oxygen in copper was just as accurate by observing the loss of weight (under proper precautions) as by weighing the amount of water formed. The author also found the former method less troublesome. Mr. Bengough asked if the samples were hammered into a thin strip and then cut up. He (Mr. Johnson) could answer in the affirmative. He, too, did not care to take samples by drilling, as one was apt to get the drillings contaminated with oil and to experience great difficulty in avoiding oxidation when drying, after cleaning. Moreover, drillings were cumbersome to introduce into the bulb. Small pieces of strip slipped in quite easily.

The use of nitric acid could not introduce the error which Mr. Bengough apprehended, since the treatment was practically instantaneous. The treatment need not be included if the strips were rolled out, since the smooth surfaces could then be cleaned with emery paper.

As proving the absence of error in employing the nitric acid cleaning, the following experiment might be cited:—

Material.	In Form of	Method of Cleaning.	Oxygen, per Cent.
Bar U.	Drillings.	Ammonia and Alcohol.	0.090
Bar U.	Strip.	Dilute Nitric Acid, Ammonia, and Alcohol.	0.089

Referring again to the matter of adding arsenic to copper as oxide or in the metallic form, he (Mr. Johnson) thought that the results of bars E and V¹ bore out his contention that neither possessed an advantage over the other. Both bars were made from "tough-pitch" ingots cast under identical conditions and after identical treatment.

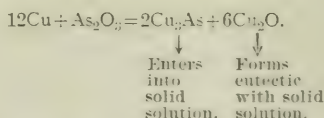
The arsenic in bar E had been added in the metallic form (as an alloy of copper and metallic arsenic); that in bar V¹ as arsenious oxide. Excess oxygen had been eliminated by "poling" in each instance. From the following record of their mechanical tests the two materials might safely be said to be identical:—

	Arsenic, per Cent.	Oxygen, per Cent.	Tensile Strength. Tons per Square Inch.	Elongation, per Cent. on 3 Inches.	Number of Alternations (Arnold).	Cold Malleability, per Cent. Reduction.
Bar E	0.36	0.06	15.70	41	190	90.67
Bar V ¹	0.34	0.05	15.75	38	190	90.67

He thought that when arsenious oxide was introduced into copper it was reduced by the latter, the alloy solidifying as a solid solution of Cu₃As in copper, surrounded by an eutectic of that solid solution with cuprous oxide.

* *The Analyst*, October 1900, pp. 253-265.

Possibly the reaction which occurred in the molten metal would be somewhat as follows:—



With regard to the determination of oxygen in brass, he (Mr. Johnson) would not recommend the same method as employed for determining oxygen in copper. Oxygen in brass existed, in all probability, as zinc oxide, mechanically entangled. In passing hydrogen over brass at a temperature high enough to effect the reduction of that oxide, steam would be formed which possibly would immediately re-oxidise the zinc vapour formed. Moreover, at that temperature the zinc contained in the brass would volatilise and would be carried by the onward sweep of the gas, and, emerging at the mouth of the tube, be oxidised to oxide of zinc.

If it were possible to use the method of reduction in a stream of hydrogen gas, very profound modifications would be necessary.

He (Mr. Johnson) thought that the ideal method would be one of electrolysis, *i.e.* to employ the sample of brass as the anode, depositing on a suitable cathode, and using an electrolyte in which oxide of zinc would be insoluble. If such an electrolyte could be obtained, the oxide of zinc should fall to the bottom of the vessel in which electrolysis was taking place, together with other impurities. It could be removed, together with those impurities, thoroughly washed, and the zinc determined by any suitable method. Assuming that the oxygen all existed as oxide of zinc, its percentage could be easily calculated. He had not heard of any such method, but thought it worth a trial if a suitable electrolyte were obtainable.

Mr. Bengough's final question was a difficult one to answer. He (Mr. Johnson) thought that the gases which were most likely to occur in solution were hydrogen and carbon-monoxide. Possibly some gas did remain in solid solution. It was not that that mattered: it was the gas which was thrown out of solution as the copper solidified which really mattered. It had a very important function in determining the "set" of copper. Of that he was firmly convinced.

He had to thank Mr. Wilson for the evidence which his own experience afforded in support of his (Mr. Johnson's) theory regarding the effect of gases released at the moment of solidification. Certainly the gases would have a maximum effect in the centre of the ingot, where the chill of the mould had not penetrated. He (Mr. Johnson) had noted with much interest that Professor Howe, in a paper read before the British Association a week after the reading of his (Mr. Johnson's) paper, had shown that very much the same thing occurred in the case of steel ingots, *viz.* that occluded gases had the effect of reducing the "piping" of such ingots.

Another point in support of the author's theory was that cast, "tough" copper had invariably a lower specific gravity than forged copper, show-

ing that the vesicular cavities had been closed up to a great extent by mechanical treatment.

Mr. Rhead had raised the same question as Professor Carpenter in connection with the micrographs, and he would refer Mr. Rhead to his reply to Professor Carpenter. With regard to antimony in arsenical copper, he (Mr. Johnson) had every reason to state that it had no injurious effect on the "hot-working" properties up to 0.20 per cent. He had made some experiments in that direction which were in need of repetition, and were not yet ready for publication. He was not yet prepared to say whether arsenic neutralised the effect of antimony. Most probably not. He could safely say that antimony was far less harmful than bismuth in pure as it was in arsenical copper. The author's brother (Mr. T. Johnson), in a paper read before the Birmingham Metallurgical Society, March 1906, had shown that copper, containing 0.5 per cent. of antimony, could be rolled hot and cold, and possessed in the annealed state a tensile strength of 15.6 tons per square inch, and an elongation of 0.45 per cent. on 2 inches.

The author himself had succeeded in preparing and drawing into wire (22 gauge) an ingot of the following composition:—

	Per Cent.
Copper	96.65
Antimony	3.28
Oxygen	0.045

He was interested to hear of the analogy drawn by Mr. Rhead between colloidal solutions and molten copper containing bismuth and oxygen. He thought that no coagulation really took place in the molten state. Copper containing cuprous oxide and bismuth was merely a homogeneous solution, just in the same way as water containing potassium iodide and, say, iodine, was. The initial stages of crystallisation consisted in the separation of pure copper from the mother liquor. The latter continuously decreased in amount as the pure copper crystals grew, becoming richer and richer until, at the point of saturation, it solidified as an eutectic, whose constituents (see micrograph 14 Q) were mutually immiscible.

The author was much indebted to Mr. W. H. Johnson and to Sir William White for their appreciative remarks.

Sir Gerard Muntz pointed to the variations in the percentages of arsenic and oxygen. He (the author) had already dealt with that point in replying to Mr. Heap. With regard to oxygen, he could not repudiate too strongly the suggestion that the percentages in the "tough-pitch" bars were erratic. The percentages were necessarily high in the "under-pitch" bars, but those had only been given as a matter of practical interest. Taking the "tough-pitch" bars containing silver, the extreme variation was 0.015 per cent., and that was mainly due to the presence of silver. Again, taking the four "tough-pitch" bars containing bismuth (KK1 to KK4), the extreme variation was 0.029 per cent., and that, too, was most certainly due to the presence of bismuth.

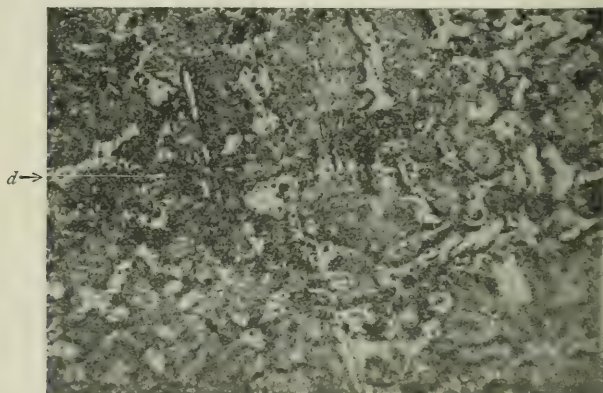
Referring again to Sir G. Muntz's remarks *re* pressure on molten copper, the author would point out that the pressure effected a closing up of the pores due to occluded gases rather than their elimination.

Had the author received financial assistance he could have ensured the percentage of arsenic being kept quite constant.

He (the author) was in accord with Professor Turner's suggestion that electrolytic and arsenical "tough" copper were two distinct things. One was copper; the other was copper dosed with phytic; and, from the engineer's, as from the metallurgist's standpoint, the treatment had proved to be beneficial for certain work.

Before concluding, he (the author) wished to make one more statement.

Referring to micrograph No. 7 (P), which represented copper exceedingly rich in cuprous oxide, he would mention that such copper when fractured showed unmistakable cubes. It had occurred to him (Mr. Johnson) that those cubes were due to the line of fracture following the spinal course of the cross-like dendrites of Cu_2O , one of which was shown in the following micrograph (No. 17 P), and in micrograph No. 7 P.



No. 17 P.—Micro-photograph showing one cross-like dendrite of Cu_2O (*d*), with eutectic and α solid solution. Arsenic content, 0.50 per cent.

Mr. G. D. BENGOUGH, M.A. (Liverpool), wrote that a further perusal of Mr. Johnson's paper had fully confirmed his first opinion of its great value and interest. It was packed full of facts and suggestions of great importance. The writer was particularly interested in the question of the solution of reducing gases, which received some attention in the paper. On page 165 Mr. Johnson referred to the solubility of hydrogen and carbon monoxide in copper. He stated that these gases were soluble in molten copper and insoluble in solid copper. Recently A. Sieverts and W. Krumbhaar* had shown experimentally that carbon monoxide was insoluble in copper, and that hydrogen was soluble in both molten and solid copper, but much more so in the former case than in the latter. With regard to hydrogen, the writer was in accord with Sieverts and Krumbhaar, and had used the fact of the solubility of that gas in solid

* *Berichte der Deutschen chemischen Gesellschaft*, 1910, 43, 893, and *Journal of the Chemical Society*, 1910, 11, 410.

copper to explain the cracking of copper heated in hydrogen gas.* If carbon monoxide were insoluble in solid copper, a similar explanation could not apply in the case of that gas. In a private communication to the writer, Professor Heyn had stated that in his experience copper did not crack when heated in carbon monoxide, and that was in accord with the results of the German authors, as far as the writer's explanation of cracking was concerned. The writer would be glad to learn Mr. Johnson's opinion in that matter, *i.e.* whether he considered that well-known phenomenon of the "gassing" of copper might be due to the presence of carbon monoxide in the gases, or whether he considered that "gassing" could only take place in the presence of hydrogen. The writer considered that "gassing" could take place in carbon monoxide free from hydrogen, though further experiments were desirable.

The section of the paper devoted to micrographic work was a most interesting one, and was quite the best known to the writer on this branch of metallurgy, which had hitherto received too little attention. In that connection it was noticeable that in none of the descriptions of the micrographs was any arsenious oxide referred to. The writer would be interested to know whether that compound was ever seen in commercial arsenical copper. In copper containing a much larger proportion of arsenic and a considerable quantity of oxygen the writer had observed crystals of that substance, but only in samples prepared in the laboratory.

The writer thought that an interesting extension of the work described in the paper would be to study the effect of the impurities dealt with at high temperatures. The effect of arsenic alone was now being studied, and the writer expressed the hope that Mr. Johnson would co-operate with him in some work on his alloys.

Mr. T. C. HUMPHREYS (Birmingham) wrote that Mr. Johnson's excellent paper on the above subject was a very useful addition to the literature on the metallurgy of copper. Its practical value, however, would have been greatly enhanced if an account of the effects of antimony in varying quantities had been included in the research, especially as that element was now so readily and accurately estimated by the distillation method. With regard to the methods of analysis, however, there were several points which might be mentioned.

Reference was made to the rapid electrolytic method for estimating copper, as described by Price and Humphreys,† and to a difficulty experienced in depositing the last traces of copper. As the author stated, the concentration of the electrolyte was an essential factor in the method, and probably his initial difficulties were caused through exceeding the volumes given.

By doubling the quantity taken for assay, *i.e.* 1 gramme instead of 0.5 gramme, the author had endeavoured to ensure greater accuracy, but it was doubtful if any advantage was to be gained, as of course the time required for complete deposition was practically doubled, and with

* *Journal of the Institute of Metals*, vol. iii. No. I., 1910, p. 51.

† *Journal of the Society of Chemical Industry*, 1909, pp. 117.

careful manipulation accurate results were easily obtained when working on the smaller amount. The ammonia test for traces on the whole residual solution would reveal 0.0001 gramme of copper if present. It was quite exceptional, however, for any to remain. That test was far more satisfactory than any method of removing portions of the solution during deposition, which must necessarily impair the accuracy of the estimation.

In the method given for estimating arsenic, if half the quantity of reagent and double the amount of metal had been taken—*i.e.* 75 cubic centimetres reagent and 2 grammes drillings and about 20 cubic centimetres hydrochloric acid added towards the end of the distillation to drive over last traces—a greater degree of accuracy would have been ensured and a considerable saving in time and reagent effected.

The method given for estimating bismuth was probably accurate for the large quantities present in the copper under investigation, but would not be suitable for the much smaller amounts usually present in refined coppers. Special precautions were required to be taken in the precipitation, and the bismuth was afterwards most readily estimated colorimetrically by the iodide method, a very good description of which is given by Rowell.* It would have been an item of interest if the author had stated his method for the separation of the iron and aluminium, as the percentages of both these elements appeared in the analyses.

Mr. D. M. LEVY, M.Sc. (Birmingham), wrote that Mr. Johnson was to be congratulated upon his paper, which was of great interest and of much importance. His contribution was likely to become a standard for reference to those interested in the question, since his investigations had been carried out on material prepared under conditions and of a nature akin to those obtaining in working practice; and he had co-ordinated the results of a series of chemical, microscopic, and mechanical tests in a manner never quite so thoroughly performed in previous work on the subject. He had, moreover, recorded observations, and deduced views from them, of remarkable suggestiveness, and had set out clearly the lines on which further research might be profitably undertaken. That all the new hypotheses which the author had arrived at from his interesting results and his clear reasoning were not entirely conclusive was largely due to conditions under which Mr. Johnson had had to conduct his work. These disadvantages were that a wholly reliable method for the estimation of oxygen in copper was not available; and secondly, that so little exact knowledge had yet been brought to light as to the amount, the condition, and the effects of the dissolved gases in commercial coppers. These two points were of fundamental importance in connection with the subject.

With regard to the question of oxygen, Mr. Johnson's paper was of special practical value in that he lays stress on the necessity for recognising the controlling effects of oxygen and the way in which it acted in conjunction with the other constituents of the metal; and though his

* *Journal of the Society of Chemical Industry*, 1908, p. 102.

view as to the sole function of the oxygen as copper oxide may hardly be accepted as final, the evidence in support of his case would direct discussion and research to a point of special interest and assist greatly in clearing it up. Meanwhile it might be suggested that the Institute would be doing a great service if a small sub-committee were appointed to carry out an inquiry into the processes for the determination of the oxygen contents in copper, and to report as to some simple and accurate method for this work.

Mr. Johnson's third conclusion (page 190) afforded useful information. The surface irregularities on an ingot of overpoled arsenical copper were usually much more marked than in electrolytic copper similarly treated, and if that be assumed to be due to the presence of larger quantities of dissolved gas being given out by the solidifying arsenical material, the observation that less cuprous oxide was required to overcome its effects was very interesting.

In view of the probability of the frequent use for reference in the future of Tables III., IV_A, and IV_B, the author would prevent any misunderstanding if he were to include the figures which show at a glance the arsenic contents of each bar, since column 2 gave no indication of its presence in the specimens.

The addition to the data in the paper of the oxygen contents corresponding to the excellent photographs, Nos. 7 (P), 8 (P), 9 (P), and 10 (P), would be of special value. No. 9 (P) would afford a check on the composition of the oxidule eutectic, which was at present taken as 3·4 per cent. cuprous oxide (equivalent to about 0·38 per cent. of oxygen). It had always appeared to the writer that in comparison with that value, the amount of oxidule eutectic revealed by the microscope in ordinary copper was very small, particularly if the proportion shown by analysis were correct.

Judging, too, from the author's photograph, No. 6 (V), Plate II., the amount of eutectic indicated for 0·182 per cent. oxygen was either very small, or else the older view that there had been an absorption of oxygen in a form other than as oxidule eutectic, might afford some explanation of the fact that less oxidule eutectic was indicated microscopically in an arsenical copper than in a metal free from arsenic but of the same oxygen content.

The author's elucidation of the joint action of arsenic and bismuth in copper, and his explanation of the scattering action on the properties of the metal, was a matter on which he was to be congratulated.

Apart from the time effect, the action of arsenic in causing this scattering of the bismuth was due to the fact that in metals carrying constituents in solid solution, solidification proceeded over a range of temperature, whilst a pure metal solidified at a definite and constant one. In the case in question that was the reason for the "cores" shown with the usual rates of cooling as indicated in photograph No. 1 (GG). Copper of gradually increasing arsenic content in solid solution separates all the time that the metal was passing through the range of temperature indicated between the solidus and liquidus curves; the "cores" repre-

senting the last portions to solidify, very rich in arsenic. The tendency, therefore, for globules of still liquid matter, such as bismuth, to be caught in between the spines which were continually being thrown out by the gradually extending dendrites was greater than in the pure material : and the scattering of the bismuth globules among the arsenical fringes of the crystals which the author's very neat piece of work has established, was the result. It would be interesting to know if the effect in the joint presence of lead and arsenic were not similar ; the insolubility and comparatively low melting point of that metal would suggest its being so. In view, too, of the analogous properties of bismuth oxides and lead oxides, the action of oxygen in improving copper containing this metal would also be explained by the formation of the oxide which converted the impurity into a form which was physically much less harmful.

The facts brought out by Mr. Johnson's research were of such importance, and his explanations had been put so clearly, that the discussion of the subject on the lines suggested by his paper should be of the greatest value to those engaged in the investigation of the problems concerning copper ; and must be gratifying to those who hoped to see in the work of the Institute the best application of scientific knowledge to practical problems.

Mr. E. A. LEWIS (Birmingham) wrote that Mr. Johnson's paper was very interesting as far as it went, and it showed a lot of painstaking work, but what was its practical value ? Did silver occur in practice in quantity sufficient to have any effect whatever on refined copper ? Did aluminium ever occur in refined copper ? In criticising the writer's work Mr. Johnson commented on the fact that oxygen was excluded as far as practicable by melting under charcoal, and went on to say that that fact was sufficient to impair the usefulness of the results from the general standpoint of works-practice. Mr. Johnson might be interested to know that arsenical copper, which would stand all engineering specifications, could be cast from a pot under the identical conditions of the writer's experiments. Works-practice was a very variable factor in the copper trade, and it was not safe to assume that all works used the same methods. The author assumed that bismuth formed an oxide of bismuth. He (Mr. Lewis) saw no necessity for it to do so, as it was more probable that it dissolved in the metallic state in the copper oxide or arsenic eutectic, and was held in solid solution. There was no need to assume it was present as a brittle oxide. The author's method of casting was open to the same objection as some earlier investigators, *i.e.* it was not done under works conditions. Ingots to make rods 4 feet by $\frac{1}{2}$ inch are not made on a commercial scale, although he had no doubt that the author got as near works-practice as possible under the circumstances. Would the same results have been got on ingots weighing one hundredweight or more ? He very much doubted if the specimens with a high bismuth content would have rolled at all.

He would suggest that the difficulties were not insurmountable, which would allow enough for two or three bars to be ladled from a refinery

furnace and the impurities added outside the furnace into a hot ladle or crucible. Perhaps some copper smelter would try some experiments in that direction. The most interesting part of Mr. Johnson's paper was the effect of silver in improving the mechanical properties of copper.

He did not agree with Mr. Johnson that aluminium had any beneficial effect on refined copper of any description. It formed an infusible oxide which was difficult to remove. It was possible that the cuprous sulphide referred to on page 201 had got in through the walls of the crucible from the coke used. It was hardly a constituent of electrolytic copper. The author said that he had no hesitation in disputing any theory which attributed the beneficent effect of arsenic to superior solvent powers of any combination of copper and arsenic for bismuth. The writer had no hesitation in saying that the author's quick-setting theory was absolutely wrong and against the weight of practical and scientific evidence. If the author's theory were true, the copper would be absolutely unworkable in the heat, even if arsenic were present. Nickel caused quick setting of copper and increased the ill effect of bismuth. The quantity of bismuth in micrograph 15 Q rendered it valueless as a means of comparison. It contained nearer one hundred times as much bismuth as should be found in good copper than ten times as much.

Why had the author done no experiments with lead, a metal that was present in nearly all commercial refined copper, and why had antimony been left out? It would have been of far more practical importance if metals had been experimented with which were met with in everyday practice. Bismuth was never found in anything like the quantity the author had experimented with, and the same remark applied to silver. Aluminium was never present in modern copper. Lead and nickel were often present. Personally, he viewed the author's experiments on the strengthening effect of bismuth with very grave suspicion. If the bars had been tested after careful annealing side by side at a constant temperature, he would have placed more reliance on them, but mechanical tests on a rod as rolled were practically valueless as a means of comparing the strengthening or weakening effect of one metal on another.

It seemed to him possible that the rolling temperature of the bismuth coppers was of necessity much lower than the samples containing no impurity and silver, and in consequence of the more severe mechanical treatment the tensile strength was higher.

Mr. R. M. SHEPPARD (Birmingham) wrote that on page 172 there occurred the statement that any variation in the percentage of arsenic present in the copper had very little effect, and that in the author's case the variation of 0.2 per cent. was negligible. He did not agree with that statement. The specification of a certain railway company for copper stay bolts required a tensile strength of 15 tons per square inch with an elongation of 40 per cent. on 8 inches. That was for an annealed cold rolled bar. In order to meet that specification 0.6 per cent. arsenic was added to the copper; if only 0.4 per cent. were added the figures would not be obtained in the tests—a fact that had been

proved over and over again in works-practice. That was shown by the bar EE in Mr. Johnson's paper, for on page 181 it would be seen that the test on the annealed cold worked bar showed a tensile strength of 14.55 tons per square inch, with an elongation of 35 per cent. on 3 inches; less than that required on 8 inches, yet that bar contained over 0.4 per cent. arsenic.

He (Mr. Sheppard) gave the following figures as an additional proof of the effect of arsenic. The oxygen contents were approximately the same in each case, and the bars had the same treatment, being finished cold rolled and annealed before testing:—

Arsenic.	Tensile Strength per Square Inch.	Elongation.
0.477 per cent.	14.70 tons.	66 per cent. on 2 inches.
0.600 "	15.58 "	47½ " 8 "

The first of these bars, it would be seen, was not strong enough to meet the requirements of the specification. The bars made with the 0.6 per cent. arsenic practically never failed in giving the figures required in the specification.

It was to be observed in Table III., page 179, that Mr. Johnson gave definite values of the elastic limit of the bars after cold working and annealing, whereas in Table IV.A. he did not do so, as stated in the footnote below the table. He would like to know if Mr. Johnson noticed any difference in the behaviour of the two kinds of bars under tension, and if cold rolling and annealing had the effect of giving the samples a definite yield point.

The author's method of preparing samples of copper for oxygen analysis, as given on page 184, would be liable, he considered, to give faulty results. Surely it would be more satisfactory to use copper filings rather than the comparatively large pieces of copper as used in those analyses. Unless the pieces were practically melted it was doubtful if all the oxygen were removed from the samples.

Bar V, referred to on page 187, was very interesting, but it was difficult to understand why it should be described as overpoled seeing the quantity of oxygen it contained. If after the air had been allowed to act on the copper the latter had been properly poled or deoxidised, surely a satisfactory result would have been obtained?

On page 187 reference was made to the quantity of oxygen required with and without arsenic in copper, and the statement appeared that "these figures only hold good for the size of casting used in this research." What difference did the size of casting make to the percentage of oxygen or arsenic required?

In the next paragraph, on page 187, the specimen R, made from electrolytic copper, was more or less condemned through no fault of its own. It appeared to have been improperly treated, the oxygen contents being too high. The figure given on page 180, Table IV.A., for the elongation, clearly showed that the sample had not been treated as well as it should. That figure should be from 55 to 60 instead of 39, and the metal should be quite ductile.

The small percentage of aluminium in bar X mentioned on page 195 had not improved the tensile strength, &c., of the copper, but it would probably be found that the metal was cleaner for working, the scale falling off easily and leaving a good smooth surface on the bar. Any large quantity of aluminium, however, as Mr. Johnson showed, had a bad effect on the hot working of arsenical copper.

Mr. JOHNSON wrote, in reply to Mr. Bengough's communication, that he was in perfect accord with him regarding the influence of carbon monoxide in the "gassing" of copper, but also believed in the solubility of carbon monoxide in molten copper.

Carbon monoxide and hydrogen either singly or together would cause copper to deteriorate when brought under their influence at high temperatures. That result was due to the reduction of those "oxidules" or particles of cuprous oxide which occur scattered uniformly throughout the metal. Pure electro-deposited copper, free from oxygen, would not be injured or "gassed" under the same conditions. Nor should arsenical copper which had been thoroughly deoxidised during the melting suffer in its mechanical properties when subjected to the influence of those reducing gases. It was the reduction of cuprous oxide with consequent formation of cavities which helped to ruin the structure of the metal. Quite reasonably one had to assume that hydrogen or carbon monoxide could diffuse through the solid crystals, even if their shattering influence were mainly confined to the intercrystalline material, viz. the cuprous oxide in the eutectic. So far as the occurrence of arsenious oxide in commercial copper was concerned, the author had every reason to believe that there was insufficient arsenic to permit of its occurrence. Copper, as Mr. Bengough himself had so well pointed out,* could dissolve arsenic, or rather the compound Cu_3As . He (Mr. Johnson) thought that with the small amount of arsenic occurring in commercial copper (usually below 0.50 per cent.) the whole of the arsenic would exist in solid solution, the oxygen separating out in the form of cuprous oxide. He had had no experience of alloys where both arsenic and oxygen were present in copper in considerable quantities. He had examined copper containing 0.50 per cent. arsenic and very rich in oxygen, and the structure of such an alloy was to be seen in micrograph No. 17 (P), shown on p. 222.

Here might be observed—

- (1) Dendrites of $\text{Cu}_2\text{O}(d)$.
- (2) Eutectic, copper-cuprous oxide.
- (3) Light areas of what was apparently a solid solution of arsenic in copper.

The author would not regard the identity of the third constituent as fully established until further experiments had been made.

The author wished to thank Mr. Bengough for his remarks, and entertained the hope of co-operating with him in high-temperature experiments as suggested.

* *Journal of the Institute of Metals*, vol. iii. No. 1, 1910.

Replying to Mr. Levy's communication, he (Mr. Johnson) had not noticed that the surface irregularities on an ingot of "overpoled" arsenical copper were more marked than in the case of "overpoled" electrolytic copper. It was a difficult thing to prove. One had to "overpole" to just the same point in each instance in order to draw comparisons.

He regretted that the arsenic contents of each bar did not occur in Tables III., IV.A. and IV.B., but they were all given in Tables VII., A to D, and were easily available for reference. He had not the oxygen contents to hand of the specimen illustrated in micrographs Nos. 7 (P) and 8 (P), but the coppers from which specimens 9 (P) and 10 (P) were taken contained 0.47 per cent. oxygen and 0.081 per cent. oxygen respectively. The former corresponded closely to the accepted composition of the Cu-Cu₂O eutectic.

Reverting to the question of the presence of arsenic coinciding with a lower proportion of oxygen than in the case of pure copper, he thought that this was due to the lowering of the solvent power of copper for reducing gases by the presence of arsenic. "Poling" could be pushed further, before the stage of "overpoling" was reached, than could be done in the case of pure copper. Hence the finished arsenical ingot would be (1) lower in oxygen-content: (2) as free, or freer, from occluded gases. The micrograph No. 6 (V) should not be taken as representative of a copper containing 0.182 per cent. oxygen, as the magnification is rather high, and the spot was chosen for making the micrograph more on account of its freedom from scratches. Another area of the same specimen under the same magnification would be richer in "oxidules."

The author's object in publishing this micrograph was to prove (1) that an ingot which had exhibited the characteristics of "overpoled" copper was really richer in oxygen than a "tough-pitch" ingot—hence micrograph No. 5 (V¹) of a "tough-pitch" ingot was given for comparison; (2) that a polished, unetched specimen readily revealed the presence of excess oxygen.

The author was greatly indebted to Mr. Levy, not only for his kind and appreciative remarks, and for the interest and care with which he had read the paper, but for his help in elucidating the point which the author had, all too clumsily, endeavoured to explain in connection with the joint action of copper and bismuth.

Owing to great pressure of work, the author had preferred to withdraw at the Glasgow Meeting the theory in the form in which it originally appeared in the paper, since it demanded further substantiation. Mr. Levy's remarks came most opportunely, because the author was convinced of the "scattering" action, whilst being unable to express his views with sufficient exactness.

Drawing a mental picture of the state of affairs in an ingot of arsenical copper, which had cooled down to that stage where "cores" of copper containing arsenic in solid solution were surrounded by the still liquid, arsenic-rich mother liquor, one could safely assume that all the bismuth would be contained in that liquid portion.

Now it appeared to the author that that arsenic-rich fringe would

solidify very nearly instantaneously, and, in addition to the imprisoning effect of the growing dendrites ("cores"), as so clearly pointed out by Mr. Levy, we might expect the bismuth to be "trapped" in minute globules in this quickly-frozen mother liquor, rather than allowed to segregate in comparatively large pools and creeks as in the case of a pure copper-bismuth alloy. This was what the author meant by the "quick-setting" effect (see page 204), although he regretted the clumsiness of his former explanation. Mr. Levy regarded the last portions to solidify as "cores," whereas the author had regarded the first portion to solidify as "cores."

Mr. Lewis, whose criticism was invited by the Institute at the author's request, attacked both the results and the *scheme* of the research.

For obvious reasons the author did not feel called upon to justify his choice of impurities. He would refer Mr. Lewis to Professor Turner's remarks, and to his (the author's) reply thereto. He would merely add (1) that silver is frequently found in some brands of copper, the author having found as much as 0.08 per cent. in one commercial brand; (2) that to the author's knowledge, aluminium has—in more than one large works—crept into a furnace-charge accidentally, with evil results, or has been employed as a deoxidising agent, with like results.

It was no matter of interest, nor was it a matter of novelty, to the author to hear that arsenical copper could be successfully cast from a crucible. He fully realised that works-practice was not based on one universal method, but it required very little technical knowledge to see that it was an advantage to employ big units. He knew that all the largest producers of refined copper, either in the ingot or the wrought form, adopted the plan of melting and refining their copper in large furnaces. In some cases the daily output of one furnace would reach 30 to 40 tons. The advantages, both technical and commercial, of dealing with large quantities, required no enumeration. To those who understood the practical control of large molten charges of copper, as the author did, Mr. Lewis's remarks about casting from crucibles would appear childish. The working costs in fuel, labour, and appliances were necessarily higher in any crucible-casting method, to say nothing of its narrow limitations as regarded quality of copper (electrolytic copper has invariably to be used), and the impossibility of refining crude copper in crucibles. One could convert crude copper into refined "tough" bars, &c., in one operation in a refining furnace. The crucible caster had to start with refined ingots, and his final product would not excel, and, in some cases, could not equal, that from a refinery.

Mr. Lewis attributed the modifying of the effect of bismuth to one of two things, believing that it "dissolved in the metallic state in the copper oxide or arsenic eutectic." The ability of copper oxide to dissolve bismuth was extremely doubtful. The author did not know of any case in the science of metallurgy where a compound would dissolve an element in the manner suggested. Perhaps Mr. Lewis knew of an analogous case. Then the statement that the arsenic eutectic could hold bismuth in solid solution was scientifically weak and based on a misconception. Mr. Lewis would do well to read up the literature of the subject. He (the

author) could definitely state that "tough cake" containing 0.60 per cent. arsenic and 0.03 per cent. bismuth had been regularly produced in this country.

Mr. Lewis suggested that "some copper smelter" should try experiments on a larger scale.

The suggestion was an extraordinary one in view of the remoteness of the possibility of any "copper smelter" being qualified to study the delicate and subtle influences of impurities in "tough-pitch" copper.

It was refreshing to learn that Mr. Lewis was actually interested in the effect of silver on the mechanical properties; his initial remarks implied that the study of the effect of this element was of no practical value.

Mr. Lewis stated that he did not agree with the author that aluminium had any beneficial effect on refined copper. He (Mr. Johnson) had not attributed any beneficial influence to aluminium; on the contrary, he had shown that its presence was quite undesirable. As Mr. Lewis stated, it formed an infusible oxide, and the presence of this oxide appeared in the analysis of bar Z, Table VII., Series D.

Mr. Lewis's suggestion that sulphur had penetrated to the small samples through the walls of the crucible had been previously entertained by the author, but it was a matter requiring proof.* With regard to the joint action of arsenic and bismuth, he (the author) would refer Mr. Lewis to Mr. Levy's remarks and his own reply.

He agreed with Mr. Lewis that lead, nickel, and antimony were elements frequently occurring in copper, and it was desirable to study their influence. For some time past he had been engaged on research in connection with these elements in arsenical copper, but his work was far from being complete. He could only state now that lead had a bad effect on arsenical copper as regarded hot-working properties, an effect which became more pronounced as the reduction of the oxygen content proceeded.

To make arsenical copper containing 0.4 per cent. lead malleable at a red heat, it was necessary to introduce so much oxygen that the metal was embrittled in the cold.

Antimony was not so bad as lead, but its influence was similar.

Nickel hardened arsenical copper, making it a more difficult matter to roll or forge it. It also seemed to encourage porosity in the cast metal.

Mr. Lewis had ignored the etiquette of the debate when he stated that he regarded the author's experiments with grave suspicion.

Facts were incontrovertible, and to suggest that the author's experiments had not been carried out under the conditions outlined was to place the argument outside the pale of scientific discussion.

He (Mr. Johnson) would merely repeat that the ingots containing bismuth and the blank bar free from bismuth were reheated side by side in the same muffle and were rolled in immediate succession, at the same

* That electrolytic cathode copper does contain sulphur (derived from the sulphate of the electrolyte) is beyond dispute.

temperature. Moreover, the strength conferred by the bismuth persisted after identical treatment in cold-working and simultaneous annealing.

Mr. Sheppard raised the question of variations in the percentage of arsenic. The figures given by Mr. Sheppard were useful, but were not conclusive proof that a variation below 0.40 per cent. affected the mechanical properties to the same extent as did a similar variation above 0.40 per cent. Mr. Sheppard's figures applied to variations above 0.4 per cent.; whereas the author's statement applied to variations below that amount. Again, Mr. Sheppard did not give the percentages of oxygen contained in his bars. A variation in this respect would account for much. He also stated that the bars with 0.60 per cent. arsenic practically never failed to give the required figures. Apparently some did fail, and it would be interesting to know why. Complete analyses were always valuable in such cases.

In this connection he would again refer to the work of Messrs. Bengough and Hill,* who found that 0.75 per cent. arsenic had no more strengthening effect than 0.25 per cent. The evidence was very conflicting, but, while thanking Mr. Sheppard for his figures, he (the author) leaned towards the belief which he had first held, unless Mr. Sheppard could produce figures fulfilling the conditions which the author had outlined, viz. :—

- (1) Variation of arsenic between 0.30 per cent. and 0.45 per cent.
- (2) Percentage of oxygen kept constant.
- (3) Gas-occlusion constant.

Regarding the figures given for the elastic limit in Table III., Mr. Sheppard raised a very interesting point. The figures given were for the first noticeable elongation, but the effect of cold-working followed by annealing was to raise the elastic limit.

As regarded preparation of the samples of copper for oxygen determination, Mr. Sheppard could rest assured that no source of error was introduced by the pieces being $\frac{1}{16}$ inch thick. Archbutt † had succeeded in determining accurately, by the same method, the amount of oxygen in a solid cylinder of copper measuring $\frac{1}{2}$ inch diameter.

Copper filings should give good results, but were open to the objections (1) that they offered a large surface to atmospheric oxidation, and (2) that they were difficult to introduce into the bulb.

It was not so difficult to understand why the ingot from which bar V was produced should be described as "overpoled." Poling was carried too far in the first instance. With the object of eliminating the surplus reducing gases dissolved in the copper more oxygen was introduced. This oxygen did not effect the elimination of the gases which caused the surface of the metal to rise during solidification. So, the metal was primarily "overpoled," oxygen was added in sufficient quantity to make the metal brittle in the cold but not to check the action of the dissolved gases.

* *Journal of the Institute of Metals*, vol. iii. No. 1, 1910, p. 40.

† *The Analyst*, December 1905, vol. xxx. No. 357.

Further poling, as Mr. Sheppard suggested, would have aggravated the case by introducing still more gases.

The difference which the size of casting made on the percentage of oxygen was apparently this. Small castings solidified much more rapidly than large ones, hence the effect of dissolved gases might be more marked in the latter case, where the prolonged cooling favoured their expulsion. The practical connection between these phenomena and the percentage of oxygen was not far to seek. The operation of poling might proceed further in the case of small or shallow ingots with these results:—

- (1) Less oxygen in finished ingot.
- (2) More gases in solution, due to the slightly prolonged poling.
- (3) The rapid chilling of the casting had not allowed the dissolved gases to escape.

In the case of bigger castings the poling must of necessity be stopped at an earlier stage: hence bigger castings might be expected to contain slightly more oxygen. With regard to bar R, that was of quite normal commercial composition, and would answer the severest commercial tests, such as the Post-Office torsion-test, when drawn into wire. Mr. Sheppard would find, on reference to Peters' "*Principles of Copper Smelting*," p. 483, that of twenty-four analyses of various commercial brands of refined copper, seventeen contained over 0·08 per cent. of oxygen. The author certainly recommended that the lower one could get in percentage of oxygen, with safety, the better.

In conclusion, the author wished to express his thanks to Messrs. Bengough, Humphreys, Levy, and Sheppard for their valuable communications.

SOME COMMON DEFECTS OCCURRING IN ALLOYS.

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THE study of what may be called the diseases of the non-ferrous metals and alloys is still in a very backward condition as compared with that of iron and steel. Several causes have contributed to produce this effect. In the first place, the number of industrial metals and alloys is so large, and their characteristic properties so diverse, that conclusions arrived at from a study of one group prove to be of little or no value when an attempt is made to apply them to another. For example, to take only two closely related groups, the results obtained from experiments on the heat-treatment of the brasses would prove useless or misleading if applied to gun-metals. This fact is of course obvious to any one acquainted with the equilibrium diagrams of these alloys, but these diagrams, which for the metallographer present such a wealth of information in a compact form, convey little to the practical metallurgist who is not versed in physical chemistry.

The manufacturer of alloys who is called on to produce a new alloy for some special purpose or to modify the properties of some familiar mixture in order to meet new requirements, has generally to grope in the dark. Variations in the mode of preparation frequently do not lead to the expected result, and fresh difficulties crop up with the introduction of even small quantities of a new ingredient, which are not to be accounted for by the known behaviour of that ingredient when alloyed with other metals. The only method of arriving at a successful result is, therefore, that of repeated trial, frequently involving, as the manufacturer knows only too well, the spoiling of many batches of metal. Even after the required result has been apparently attained, subsequent charges of the alloy

are apt to develop mysterious defects, although they were believed to be prepared by exactly the same method.

Moreover, the manufacturer's difficulties are not over when he has delivered his product in an apparently satisfactory condition. He may, and frequently does, hear that the alloy has failed in practice after having passed the specified tests, and the failure is generally attributed to the defective quality of the alloy. This is, of course, sometimes the case, latent defects having revealed themselves under the conditions of practice; but it also happens very frequently that a perfectly satisfactory alloy fails through being subjected to entirely unreasonable heat-treatment or mechanical straining in the course of being fitted for use. Such treatment is applied in ignorance of the effect likely to be produced, and, considering the care that is taken in handling steel, it is remarkable that non-ferrous alloys are often treated as if they were mere inert material, which might be ill-treated without suffering any injury.

For instance, whilst no user of metals would quench a steel from a high temperature, or submit it to prolonged annealing, without reference to the purpose for which it was required, it is not an uncommon experience to find bronzes of a special character treated in such a way. Here, again, a knowledge of the equilibrium diagram indicates what is to be done and what is to be avoided. It may be said that most of the users of steel are quite innocent of any knowledge of the highly complex conditions of equilibrium in the alloys of iron and carbon, and this is no doubt true: but the experts who have chiefly developed our knowledge of the properties of steel have made full use of metallographic methods, and it has been found possible to put their conclusions into a more or less simple form for each particular variety of steel, the user of which thus obtains the results of tedious and complex researches in the shape of simple practical rules. The same course must be followed in respect to other alloys. We cannot expect every maker and user of non-ferrous alloys to become familiar with the intricacies of the equilibrium diagram; but it is important that a very thorough study should be made, by those competent to undertake it, of the

effect of heat and mechanical treatment on each important group of alloys, and of the effect of smaller quantities of other elements on them, due regard being paid to the constitution of the alloys as revealed by a metallographic study. Very few studies of this kind are yet available. I may refer to the investigations of Curry and others in America⁽¹⁾, of Guillet in France⁽²⁾, and of the Alloys Research Committee in this country⁽³⁾ on the various types of bronze, and of Messrs. Bengough and Hudson⁽⁴⁾ on the brasses, as excellent examples of what I mean. A beginning has thus been made, but it is obvious that an enormous amount of experimental work will be necessary before such alloys can be used under varied conditions with the same confidence as steel.

Too much must not be claimed for the equilibrium diagram, but the objection that it represents only ideal conditions of equilibrium, which are never attained under industrial conditions, has very little force, as it is possible to infer from it, with a considerable degree of accuracy, the effect of such thermal conditions as are realisable in practice. Another objection is that only alloys of two or three metals can be fully represented by such means, whilst a large number of industrial alloys contain at least small quantities of other elements. When, however, the binary and ternary systems are sufficiently well known, allowance can generally be made, with a fair approximation to the truth, for the effect of additional components.

The following classification of some of the common defects observed in alloys is by no means exhaustive, and is only intended as a preliminary review, to serve as a basis of discussion. The Institute of Metals has recently undertaken the formation of a museum illustrating the "diseases" of metals, and it is to be hoped that members who meet, in the course of their experience, with interesting instances of metals or alloys which have developed marked defects in use, or which have been spoilt by improper treatment, will send specimens for the museum, accompanied by as full a statement as possible of the exact conditions under which they were obtained. In this way a most valuable mass of informa-

tion should be accumulated, on which it would be possible, if not to base generalisations directly, at least to decide on profitable lines of investigation. The interchange of experience relative to such questions as these is already common in the iron and steel industry, and has proved of inestimable value, and it is to be hoped that the meetings of this Institute may facilitate and encourage a similar practice in the industry of the non-ferrous metals, which has hitherto been shrouded in an atmosphere of considerable mystery.

One cause of alloys being found defective in practice is here omitted, namely, the use of an alloy of unsuitable composition. It is assumed that the intended composition is a proper one for the purpose for which the alloy is to be used. This limitation is necessary in order to avoid entering a much wider field than could be dealt with in a short paper.

The first class of defects includes those which are present in the original casting, and may be classified as (1) sponginess, due to the enclosure of gas; (2) brittleness or weakness, due to the presence of (a) oxides or other drossy matter, (b) intercrystalline metal or eutectic alloy.

1. Sponginess is caused by gases, dissolved in the molten metal or alloy, being released at the moment of solidification. Unlike other liquids, molten metals dissolve more gas as the temperature rises⁽⁵⁾, so that the more the metal or alloy is overheated before casting, the more gas it will dissolve; and, as such solutions easily remain supersaturated, an overheated metal will usually contain more gas at the moment of pouring than one that has only been heated to the proper casting temperature. This defect may, of course, be corrected by re-melting and pouring at the proper temperature. Blisters in rolled sheet metals are generally due to this cause.

Gas-pores are frequently microscopic, and are only to be detected in a prepared section, which is preferably examined without etching.

2. (a) The presence of oxides or dross may be due to insufficient care in pouring, allowing dross to be carried into the mould along with the metal, or to overheating, causing burning, especially in the case of zinc alloys. The oxides of different metals differ widely in their tendency to separate from the

alloy and to rise to the surface. Copper oxide is the only one which dissolves in the liquid to any appreciable extent, hence its effect on an alloy is not that of a dross, but falls under (2 *b*). Zinc oxide is friable, and remains entangled very easily, which is the reason why a deoxidiser is added in casting brass and similar mixtures. Tin oxide forms well-developed crystals^(v), which are hard and brittle, and give rise to planes of weakness. Aluminium oxide is difficult to eliminate, and has a remarkable tendency to form thin pellicles, surrounding drops of the liquid, and these drops are thus prevented from uniting. Pure molten aluminium always appears to be enclosed by a thin skin, and this behaviour is also exhibited by its alloys. The oxide of magnesium resembles that of zinc, and its presence in nickel often causes cracking when the metal is rolled, if magnesium has been used to deoxidise. On the other hand, the three remaining deoxidisers of importance—manganese, phosphorus, and silicon—form oxides which are readily eliminated in the form of slag, on account of their great reactivity, which enables them to combine with some of the constituents of either the crucible or the flux, to form fusible compounds. Brittleness due to the enclosure of oxides is thus prevented by using one of the last three deoxidising agents in casting. Alloys of copper and nickel, for instance, which often crack in rolling owing to the presence of oxide, are perfectly malleable if deoxidised with cupro-manganese.

The detection of oxides by means of the microscope requires care, as the exceedingly friable nature of these substances causes them to break out of the surface during polishing if emery paper is used, leaving cavities in the place of the original oxide particles.

(*b*) The second source of brittleness named above is the presence of thin layers of a eutectic alloy between the crystals, producing discontinuity. This occurs when an impurity is present which forms a fusible eutectic with the other constituents. A characteristic example is seen in the effect of bismuth on copper or alloys of copper, the eutectic (which in this case differs little in composition from pure bismuth) forming highly brittle layers between the crystals of copper, which are therefore easily separated by shock. A very minute

quantity of antimony also renders brass cold-short. The remarkable brittleness produced by the addition of mere traces of lead or bismuth to gold, observed by Roberts-Austen, is accounted for in the same way.

The microscope is of great assistance in studying such cases as these, although skill is required to render minute quantities of eutectic visible in a soft tough metal, such as copper. When the proportion of eutectic is small, it usually appears under the microscope as a single substance, owing to segregation of the constituents.

The brittleness caused by the presence of intercrystalline matter may not show itself at all temperatures, but may only become perceptible when the alloy is subjected to stress at a high temperature. This is of particular importance in the case of fire-box stays, and also in that of the bronzes used for valves and other steam-fittings. Lead is frequently added to such bronzes in order to increase the ease with which they are worked, but the amount of lead which can be held in safety by bronzes is very small, and any excess above the limit causes rottenness at the temperature of the steam.

An impurity which enters into the alloy in the form of a solid solution, instead of forming a eutectic, is not visible on microscopical examination. Such an impurity does not produce brittleness if only present in small proportion, but may nevertheless have a fatal effect on certain physical properties, especially on the electrical conductivity.

3. *Defects due to inequalities of composition.*—These may be due to (a) imperfect mixing of the ingredients; (b) separation by gravity during solidification; (c) segregation in the mould.

(a) When there is a difficulty in mixing the ingredients uniformly, the usual cause is their difference of specific gravity, a light metal, such as aluminium, having a marked tendency to float, whilst a heavy one, such as lead, sinks. In addition to this, the property of certain metals, particularly aluminium, of becoming enclosed in a film of oxide as soon as molten, is a difficulty in the way of obtaining a uniform mixture. There is also the case of metals which do not mix when molten, but behave like oil and water. If sufficiently stirred they may be

brought into the form of an emulsion, but the extent to which separation into two layers takes place again will depend on the rate of cooling. Lead only dissolves to a very small extent in most bronzes, and if allowed to cool slowly will collect in the lower part of the ingot, which thus contains more lead than the upper part.

In a few instances an emulsion of different metals is deliberately prepared, as in the plastic bronzes used for bearings. These consist of a bronze meshwork holding lead in the cavities. The quantity of lead far exceeds that which can be held in solution in the liquid state, and unless casting is carried on under the proper conditions, the emulsion tends to separate, and lead becomes concentrated in the lower part of the casting.

(b) The most familiar example of the separation of constituents by gravity during solidification is that of the alloys of tin and antimony, or bearing-metal mixtures containing those metals. The cubes of the tin-antimony compound are the first to crystallise, and tend to float up to the surface, becoming almost entirely concentrated in the upper part of the casting. This is avoided by chilling rapidly.

(c) The segregation of impurities in steel ingots has been the object of repeated study. The only case which has been thoroughly investigated in the non-ferrous alloys is that of gold and silver bullion⁽⁷⁾. In general it may be said that those impurities which form fusible eutectics, such as lead and bismuth, in the bronzes, will accumulate in the central part of the ingot, thus producing unsoundness in large castings, even when the proportion of impurity, calculated on the whole mass, is not excessive.

Hard phosphor-bronzes are often defective through lack of uniformity in their composition.

4. *Excessively coarse structure, due to casting at too high a temperature.*—This defect is dealt with in Mr. Primrose's paper for the case of gun-metal. As the strength of an alloy depends on the degree of interlocking of neighbouring crystal grains as well as on their size, the dependence of strength on casting temperature and degree of chilling is of a complex kind. The conditions governing crystallisation demand much further investigation. A few alloys, such as the β -solid solutions

in the copper-zinc series rich in zinc, have an extraordinary tendency to form large crystals having little mutual adhesion.

5. *Defects due to wrong thermal treatment.*

(a) Quenching from a high temperature. Leaving aside chilling cracks, which fall into another class, the principal effect of erroneous treatment in this direction is the production of large crystal grains (coarse structure) in alloys in general, and in most of the bronzes, of a hard, brittle constituent in a more or less unstable state. For example, alloys of the Muntz metal class, and certain of the tin and aluminium bronzes, which normally contain two micrographic constituents, are changed by quenching from temperatures above a certain limit into a single solid solution. Such alloys are harder and stronger under ordinary loading than the normal alloys, but at the same time they are more brittle, and less resistant to shock. The coarse fracture and the peculiar "crinkled" surface of tensile test-pieces of alloys treated in this way are very characteristic. Occasionally such quenching is intentionally resorted to, in order to increase the strength at the cost of some sacrifice of ductility, but the treatment is not without its dangers, and error in the quenching conditions may render the alloy brittle.

(b) Heating at too high a temperature or for too long a time during annealing. The dangerous coarseness of grain produced by such treatment is well known. Reference may be made to the memoirs already cited.

(c) "Burning" in the case of alloys of copper and zinc. There are differences of opinion as to the cause of this defect occurring at high temperature. I am inclined to regard the burning temperature as that at which the zinc held in solid solution has a certain appreciable vapour pressure.

(d) Unequal thermal treatment of different parts of the same casting or forging, producing differences of structure and of size of grain.

All the defects enumerated under (4) may be detected by means of the microscope, provided that the constitution of the alloys is known. Deviations from the size of crystal grain found best for any specified purpose may be measured and recorded.

6. *Defects due to molecular change, other than that produced by mechanical stress.*—Some metals undergo allotropic changes, involving a complete alteration of properties, at definite temperatures. The most striking instance is that of tin, which is metastable below 18° , and may pass spontaneously into a grey powdery modification, devoid of mechanical strength at lower temperatures. Whilst grey tin is only a laboratory curiosity in this country, the "tin plague" is the source of serious inconvenience and loss in such cold countries as Russia (⁸).

It appears, moreover, that tin is capable of undergoing another change at the temperature of a warm room, being transformed in course of time into coarse, loosely adherent crystals. Like the tin plague, this disease may be caused to spread through a mass of ordinary tin by inoculation (⁹).

The spontaneous disintegration of alloys has been described very frequently. Many of the alloys of aluminium with other metals fall to powder after a time, whilst an alloy of 80 per cent. aluminium and 20 per cent. tin breaks up into coarse crystals (¹⁰). It is doubtful whether this behaviour is really an instance of molecular change. It would be interesting to observe the behaviour of alloys prepared on the small scale from pure materials, and with special precautions to avoid contamination with carbon, silicon, or gases. The importance of this condition is seen on comparing the case of the alloys of copper and manganese, which have been described as disintegrating spontaneously. When prepared with pure materials, however, they are perfectly stable, and the disintegration is entirely due to the presence of non-metallic impurities.

Some solid solutions undergo a molecular change at a critical temperature in such a way that only a few of their properties exhibit any alteration, as in the remarkable magnetic bronzes described in Mr. Ross's paper. So far as is known at present, such transformations are not accompanied by any change of crystalline form, although this may only mean that our methods of discrimination are not sufficiently delicate. Until lately, it was impossible to distinguish α , β , and γ -iron microscopically, but the beautiful work of Rosenhain and Humfrey (¹¹) has shown that the application of

stress reveals the crystallographic differences with wonderful clearness. It is quite possible that the great and sudden diminution of strength which most bronzes and other copper alloys exhibit at moderately high temperatures may be due to some such molecular transformation, and an application of this method might reveal differences of crystalline structure which have hitherto passed unnoticed.

A great variety of defects are due to mechanical rather than to chemical causes. These include:—

7. *Shrinkage cracks*, which may be due to the unsuitable arrangement of the mould, to a wrong temperature of casting, or to great brittleness of the alloy at a temperature just below that of solidification. The latter condition is the cause of the great tendency of aluminium-zinc castings to crack during cooling.

8. *Defects due to molecular change produced by mechanical deformation.*

(a) *The Brittleness of Cold-worked Metals.*—The cause of the hardness of cold-worked metals and alloys has been shown by Dr. Beilby⁽¹²⁾ to be the formation of an amorphous, unstable modification. This gives rise to a number of defects, a few of which may be enumerated:—

- (i.) “Season-cracks” in brass and other alloys, showing themselves some time after rolling. In this case the outer layers are in a more highly strained condition, and are more largely converted into amorphous material, than the inner portions, and cracks develop on the surface, spreading inwards.
- (ii.) “Fire-cracks,” which differ from the foregoing in appearing only during the annealing process. The reconversion of the amorphous into the crystalline modification is accompanied by a change of volume which may cause cracking if the external and internal layers differ greatly in their state of strain. The most usual course of fire-cracks is therefore the application of insufficiently heavy “pinches” in breaking down, resulting in the formation of a severely strained outer layer, whilst the internal portions are only slightly affected. It is said that fire-cracks never appear in

pure metals, whilst they are very characteristic of solid solutions. German silver is particularly liable to this defect.

It is remarkable that the state of strain referred to may be partly removed by shock. Thus, in order to prevent the development of fire-cracks, brass and bronze rods are "sprung" by bending sharply, coils of wire are "whipped," and heavier objects are "belted" with a wooden mallet. The removal of strain effected in this way recalls the effect of shock on magnetised steel, and is no doubt connected with the re-orientation of the molecules, as studied by Ewing⁽¹³⁾.

- (iii.) When there is no inequality of strain, but the material has been very severely worked, as in articles spun from sheet, the crystals are very largely converted into the amorphous modification, and the tendency to recrystallise may be so pronounced as to set in spontaneously, or apparently so, especially if assisted by vibration. Some remarkable examples of the recrystallisation of spun brass have been studied lately by Cohen⁽¹⁴⁾, who has shown that a piece of strained metal may be caused to crystallise by "inoculating" it with particles of crystalline metal. The "strain-disease" (*Forcierkrankheit*) is therefore, like the tin plague, contagious. This is, of course, in accordance with the physico-chemical view that the hardened material is a metastable modification, and therefore tends to be transformed in contact with the stable form.

(b) Chilling-cracks, produced when metals are suddenly quenched. These cracks are also due to differences in strain, produced in this case by the rapid cooling, and consequent contraction, of the outer layers.

(c) Cracking during hot-working. Most alloys show an increased brittleness at some characteristic temperature. Many bronzes have only a small range of temperature within which they may be safely worked. The connection between these temperatures and the constitution of the alloys has been very imperfectly investigated.

The recognition of conditions of strain in metals and alloys is best accomplished by means of physical tests, their microscopical study being a matter of great technical difficulty.

There remain a few defects which arise in the course of the use of alloys, and do not fall under one of the above heads:—

9. *Corrosion*.—The whole problem of the corrosion of alloys in the course of wear is very complex. Fortunately, a special committee of this Institute has been formed to collect data bearing on the subject, and to conduct further investigations, and it is therefore unnecessary to make further reference to the matter here. It may be permissible, however, in connection with what has been said under (7) to point to the differences of potential which exist between the strained (partly amorphous) and the crystalline modifications of the same metal or alloy as a factor which has so far hardly received sufficient attention ⁽¹⁵⁾.

10. *Erosion*.—The conditions which affect the liability of alloys to mechanical erosion also demand further study. A case of the greatest importance is that of the erosion of high-speed propellers by the action of eddies. Some remarkable specimens, now to be seen at the Japan-British Exhibition, showing patches near the middle of each blade eroded to a depth of as much as $1\frac{1}{2}$ inch whilst the rest of the blade is quite smooth, illustrate the necessity for a thorough study of this question. It appears that certain bronzes are not liable to the defect—at least in the same degree; and it is very desirable that a relation should be established between the microscopic structure and the liability to erosion.

Other forms of erosion, produced by solid particles in suspension, also depend in a little explained manner on the internal structure of the alloy.

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METALLOGRAPHY AS AN AID TO THE BRASSFOUNDER.

BY H. S. PRIMROSE

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PRACTICAL metallography, although not yet raised to the status of an exact art, is gradually coming to be regarded as a valuable aid to the chemist in a well-equipped works making non-ferrous alloys. The microscopical investigation of the structure of alloys is largely superseding the method of judging quality by fracture, and is undoubtedly a more certain guide to the foundryman who wishes to escape the repetition of serious failures due to causes other than change of chemical composition.

The text-books dealing with the subject mostly take up the theoretical side of the constitution of the alloys, many of which have little or no practical or industrial value; and those which do not fall into this category are usually only given as examples of good or selected specimens. Thus metallography, as applied to the needs of the brass or bronze-founder, still lacks the needed degree of standardisation, and the object of this paper is to discuss some outstanding cases met with in a large workshop practice, in which the pathological examination of a few failures and defective gun-metal castings has been not only instructive, but of considerable utility in discovering what faults to avoid, more particularly when chemical analysis afforded no clue.

The usual standard to which most foundries have to work is governed by rigid specification of the tensile strength and elongation of test-bars from the castings produced, and whilst this method affords a valuable check upon the acceptance of faulty workmanship, failure generally results in throwing the onus on to the metal, but most cases of microscopic examination reveal the fact that structural deficiencies are to blame. The ultimate strength and degree of elongation which a metal possesses depends entirely on the nature of the crystalline

arrangement, and this, in turn, depends upon the rate of solidification, as also to a less extent on the rate of cooling after solidification. For each metal or alloy there is a certain size and arrangement of crystal grain which gives maximum strength and durability. If this be exceeded, then there is not sufficient interlocking of the crystals, and thus large cleavage planes are formed, but if the crystal grain be too small, the interlocking may be so minute as to be almost valueless.

As the appearance of a fracture depends largely on the way it is made, its practical value is very limited. If the structure is macroscopic and visible to the naked eye, it usually indicates a too coarsely crystalline structure, or that the specimen has been broken hot, as is shown in Fig. 1, Plate I., which represents the holocrystalline structure of a gate of a gun-metal casting reproduced natural size. When the structure is of fine grain a hand-magnifier may be used, but this reveals nothing of the real or internal structure, for investigating which a microscope must be employed. To avoid the difficulty of focussing even the smoothest parts of the fracture, it is necessary to prepare a plane surface of the metal, and this is done by polishing. Care must, of course, be taken to ensure that the polished surface is kept perfectly level, and "hog-backing" especially should be avoided. File-marks and scratches are removed by application of successively finer emery-papers, but most copper rich alloys are so excessively soft that even the finest "000" French emery-paper and the most delicate touch will leave markings which will obscure the structure. The excessive precautions recommended for the final polishing of specimens intended for research work are not always necessary for workshop practice, or as a foundry check. A quite satisfactory final polish can be imparted by the use of a "Selvyt" cloth, stretched upon a polishing disc, moistened with water carrying a small amount of diamantine polishing powder in suspension. The development of the structure is variously accomplished, but the structure is most usually revealed by etching with alcoholic solution of ferric chloride, copper ammonium chloride, &c., and recently heat or oxidation tinting has been coming into vogue. This treatment attacks the various constituents at different rates, and

the process must be stopped immediately the mirror brightness of the surface has been destroyed. This often distinctly shows the orientation of the crystals to the naked eye, but when this is not the case a low magnification of 20 or 30 diameters, using oblique illumination, will almost surely do so. Sometimes this orientation is also visible by vertical illumination, and is shown in Fig. 2, Plate I. The most definite results are, however, obtained by vertical illumination, which is got by a small reflector placed in the tube of the microscope, which, for ordinary work, may be of quite cheap construction, as the magnifications usually employed are low. If photographic records are desired to be kept, or when special investigation is required, it is usually advisable to employ a more scientific instrument, such as the Rosenhain metallurgical microscope, made by Messrs. Beck of London. The difficulty of photographing is not great, as all the necessary lenses are present in the microscope combination, camera bellows only being required. In this case it is found best to examine the projection of the specimen on the screen rather than the optical image, and whilst the etching colorations give a better idea than a photograph, the latter is permanent, and can be subsequently referred to.

The photomicrographs of gun-metal specimens reproduced at the end of this paper (which photomicrographs are reduced 25 per cent. in reproduction) are all taken from test-bars which were attached to actual castings, and subjected to tension to determine tensile strength and elongation. The composition of the specimens is that of the usual Admiralty gun-metal, viz.—88 per cent. copper, 10 per cent. tin, and 2 per cent. zinc. The castings were made in dry-sand moulds, and as nearly as possible all under the same conditions of cooling.

With gun-metal castings the temperature of pouring has a great influence on the strength of the finished castings. The chief cause for the differences which exist in the quality of the metal is the different rates of cooling and freezing. In the case of the pouring being at a high temperature, just before freezing commences, the sand of the mould becomes highly heated, and so the freezing of the metal is slower than when the metal is not so hot at first, and hence the crystals

have time to grow and form a good strong interlocking structure. This is well shown in Fig. 3, Plate I., which is the photomicrograph of a test-bar from a casting poured at 1100° C. and slowly cooled. A similar bar cast at a much lower temperature (950° C.) was cooled much more quickly, and in this instance not only have the crystals been prevented from growing, but the constituents of the metal have remained practically in a state of solid solution with no well-defined structure, which is seen to be unresolved by the higher magnification of 150 diameters in Fig. 4, Plate I. The differences in the tensile strength and elongation of the two pieces is also very well marked, showing the difference in strength of the two pieces of metal.

As the two casts are of practically the same composition, it follows that the variation in the temperature of casting, and hence the consequent rate of cooling, has had a very distinct effect in the structure or crystalline formation of the metal. In castings which have to stand the test of a high-water pressure the interlaced type of structure is important, so that the temperature of pouring such castings has to be carefully watched. If it is too low when run, the resulting casting will be porous and weak, and will not stand even a moderate pressure of, say 80 to 100 pounds per square inch, instead of the necessary pressure of 700 pounds and upwards. The reason for this is obvious from a consideration of the micro-structure, as the interstices of the light-coloured copper-rich ground mass (Fig. 3) have been filled in with small land-locked seas of eutectic, and thus soundness results, but with the quick uniform contraction of the solid solution, intercrystalline pores have been developed, and show as microscopic holes throughout the poor metal (Fig. 4). Following on this, it would appear that to get the same quality in all castings, the metal for large and thick castings should not be so highly heated when cast as that which is used for much thinner work. Thus the casting temperature of gun-metal is not a constant, but must necessarily vary with the weight of the casting, as well as its internal and external form, and the number of branches, arms, and projecting parts on the casting. Now if the founder is careful and bears this fact in mind,

many difficulties can be overcome by arranging his moulds of dissimilar castings, so that those of a light nature are cast first with hot metal. It is evident that by using a ladle a great variety of casting temperatures can be got, and occasional pauses may be made between some of the moulds if the temperature is too high for the nature of the work.

Excessively rapid cooling has the effect of rendering gun-metal very brittle, and almost steel-like in appearance and hardness. A sample quenched from just below solidification-point evinced a very marked change in structure, as shown in Fig. 5, Plate II., and this required a high magnification (240 diameters) to show the copper separated in almost pure crystallites, surrounded by a ground mass of eutectic which is of a hard brittle nature.

The existence of blow-holes in gun-metal weakens the castings to a very considerable extent. The presence of the blow-holes may be due either to slight dampness in the mould when the metal is cast into it, or the gases which form these holes may be actually dissolved in the metal when it is cast. They are often a great source of trouble to the founder, casting after casting having to be scrapped on account of such holes, which usually do not show until the casting comes to be machined. They are often quite small, and, as shown in Fig. 6, Plate II., they are unequally scattered through the field, and it can easily be understood how the tensile strength of the metal is reduced on account of these holes, even although the composition is perfectly correct and the metal has been properly melted. A microscopical examination is the surest way of ascertaining the cause of blow-holes. If these are clean and confined to the outer portion of the castings, they are certain to be due to the steam formed within the mould, in which case a simple remelting brings the metal right. Fig. 7, Plate II., shows some blow-holes near the side of a casting due to steam, and also how the internal structure has been altered by the too rapid cooling. Fig. 8, Plate II., shows the improved structure of the metal after remelting.

More often the pin-holes in castings appear dirty under the microscope, and on polishing, some brittle material is rubbed out, causing serious scratching of the surface. This is due to

segregations of included oxides either of tin or copper, which the small percentage of zinc has not been able to remove. Under this condition remelting is of no avail unless with the aid of some deoxidising agent such as phosphor tin or phosphor copper. This need only be added in very small proportions, and which of these is employed will depend on whether the copper or tin is deficient. Their action is due to the phosphide attacking the dissolved oxides, reducing them to metal, and the phosphorus escapes as pentoxide. Figs. 9 and 10, Plate III., show interesting photomicrographs of 10 per cent. phosphor tin and phosphor copper, illustrating the structures of the two phosphides and the accompanying brittle eutectic.

The test-bar of which the photomicrograph is given in Fig. 11, Plate III., only withstood an ultimate stress of 8.6 tons per square inch, and on microscopical examination evinced several patches of very indefinite structure pitted with cavities in which oxide inclusions remained. This metal on remelting with about 0.5 per cent. of the phosphor copper, gave a casting which stood over 16 tons per square inch, and showed 24 per cent. elongation on a 2-inch test-bar. This small quantity of phosphorus was evidently not only sufficient to remove the intermixed oxides, but also to leave a trace of phosphorus in the metal. This is indicated by the good structure shown in Fig. 12, Plate III., the higher magnification of which shows the increased proportion of separated eutectic due to the small amount of phosphorus present.

It is not often that gun-metal is cast from large furnaces or ladles, but when this is done in large workshop practice special precautions must be taken to ensure the uniformity of the metal from beginning to end of the cast. Segregation does not so readily take place, but with a great weight of metal in the ladle some scum and dirt is apt to be intermixed; the removal of this is somewhat troublesome, even with stirring and the addition of deoxidisers, unless a billet of green-wood is used to agitate the metal. The stirring is sometimes done by a so-called "secret process," which consists in stirring the metal with an iron rod to the end of which an ordinary raw potato is affixed.

The heat-treatment of gun-metal is a subject which as yet has not been fully investigated, but the results got by M. Guillet and others on the heat-treatment of the copper-tin alloys show that with the useful bronzes, profound changes are effected by varying temperatures of annealing and quenching. Now if gun-metal were subjected to a similar treatment, it is more than possible that equally remarkable changes would be got, and it is proposed to make this the subject of a future paper.

The constitution of the binary alloys of copper with tin and also with zinc has been very thoroughly worked out, but there is still scope for useful research on their ternary alloys, especially in the region rich in copper. When one considers the large number of commercial alloys of this composition, it is surprising that no systematic investigation has been made in regard to the strength and durability of what Professor Thurston calls the "kalchoids." The addition of zinc to ordinary bronze not only improves the colour, but makes the alloy cast much better. Without materially altering the structure, the zinc prevents the formation of a certain small amount of eutectic, and also acts as a deoxidising agent for any trace of copper or tin oxide dissolved in the metal. This is clearly demonstrated by comparing Figs. 13 and 14, Plate IV., which proves how cavities can occur in the segregated eutectic from a bronze containing 88 per cent. copper and 12 per cent. tin (Fig. 13), whereas in the gun-metal with 2 per cent. of zinc alloyed to the 88 per cent. of copper and 10 per cent. of tin these are entirely absent (Fig. 14).

Whilst the pyrometer is of great service in determining the temperature of the metal before pouring, it is not practicable to take the rate of cooling of each casting. Hence it often occurs that perfectly sound metal gives test-bars which fall just short of the required strength, and the reason for this is another point easily explained by the microscope. Fig. 15, Plate IV., shows quite a remarkable instance of the copper crystals having grown too rapidly in certain directions, and thus the required amount of intertwining has not been effected, with the result that the tensile strength is somewhat low. Fig. 16, Plate IV., shows a pronounced case of rather fine-

grained structure almost devoid of interlocking, which possessed low tensile strength and elongation, also due to incorrect cooling of the metal. It is likely that a suitable annealing would have promoted diffusion and brought the strength of these two castings up to a very much higher standard.

In the examination of gun-metal test-pieces under the microscope, the comparison of the various structures shows very clearly the difference between the good and bad pieces. Whenever the structure is of a good interlocking crystalline type, as shown in Figs. 3, 8, and 12, the strength of the metal is always good, possessing a tensile strength of 15 tons per square inch and upwards, with an elongation of 20 to 25 per cent. on 2 inches. On the other hand, whenever the structure appears as in Figs. 4, 6, 7, and 11, it is easily understood how the tensile strength comes to be low. In these latter cases the metal is weakened either by the presence of gas in the form of blow-holes, or else the casting is devoid of the good crystalline arrangement which gives the metal its strength.

This comparison very quickly enables the necessary experience to be acquired for determining the cause of the troublesome defects should such occur, and this is more than half the battle in the direction of putting things right again. Whilst there is still some controversy in regard to the interpretation of the results of the metallographic examination of certain of the bronze alloys, there need be little fear of dubiety in investigating any of the useful alloys from the pathological standpoint. Care, of course, should always be taken to ensure the proper sampling of the test-piece, avoiding any portion which has been subjected to undue stresses; but, on the other hand, the structure right at any point of failure may be examined with benefit, since it is through profiting by the investigation of faults that ultimate success is achieved.

The author has to express his grateful acknowledgment to Messrs. G. & J. Weir Limited, Cathcart, for their kind permission to publish these notes and the photomicrographs prepared in the course of their laboratory testing.

The following table gives full particulars of the composition and physical properties of the specimens illustrated by the photomicrographs:—

Fig. No.	Material.	Analysis.			Tensile Strength. Tons per Sq. In.	Elongation per Cent. on 2 Inches.	Remarks.	Microstructure.
		Copper, per Cent.	Tin, per Cent.	Zinc, per Cent.				
1	Gun-metal, gate	88.0	10.0	2.0	...	...	Broken hot	Highly crystalline fracture.
2	Gun-metal, bar.	88.0	10.0	2.0	18.6	24.0	Very good metal . .	Well-defined orientation.
3	" "	88.0	10.0	2.0	16.4	25.0	Good standard metal	Good crystalline structure.
4	" "	87.4	9.7	2.7	11.0	4.5	Poor metal	Very bad structure.
5	" (chilled)	88.0	10.0	2.0	...	...	Sample from vent . .	Brittle eutectic structure.
6	" bar.	88.0	10.0	2.0	9.8	3.0	Very weak metal . .	Badly pitted structure.
7	" "	87.6	9.7	2.6	5.0	...	Very faulty metal . .	Defective structure and blow-holes.
8	" "	87.8	9.8	2.3	16.0	...	Good metal. No. 7 remelted	Strong interlocking structure.
9	Phosphor tin	...	...	...	...	...	.....	Tin, with phosphide of tin crystals and eutectic.
10	Phosphor copper	...	...	...	...	...	.....	Phosphide of copper crystals in copper phosphide eutectic.
11	Gun-metal, bar.	88.0	10.0	2.0	8.6	7.5	Burnt metal. . . .	Poor metal, with oxide inclusions.
12	" "	88.0	10.0	2.0	16.1	24.0	Very strong metal. No. 11 remelted	Excellent structure.
13	Bronze (cast)	88.0	12.0	...	12.0	5.0	Hard coinage metal .	Good structure, but pitted.
14	Gun-metal, bar.	87.8	9.8	2.3	16.0	19.0	Good casting metal .	Very good structure.
15	" "	88.0	9.8	2.1	13.4	12.5	Medium good metal .	Insufficient interlocking.
16	" "	88.0	10.0	2.0	9.5	5.0	Poor metal	Fine grain; almost no interlocking.



FIG. 1.—Gun-metal Fracture. Natural Size.
Oblique Illumination.

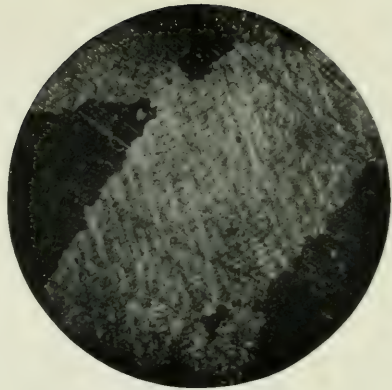


FIG. 2.—Gun-metal Test Bar.
Magnified 20 diameters.

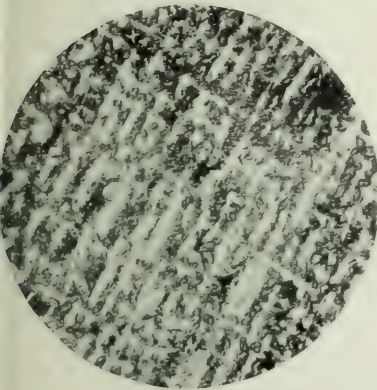


FIG. 3.—Gun-metal Test Bar.
Magnified 60 diameters.

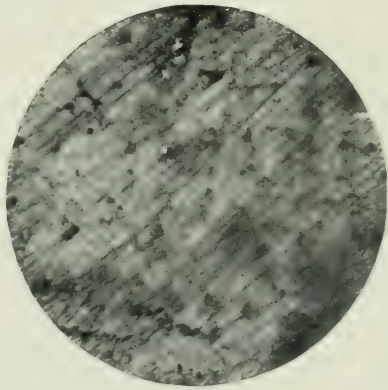


FIG. 4.—Gun-metal Test Bar.
Magnified 150 diameters.

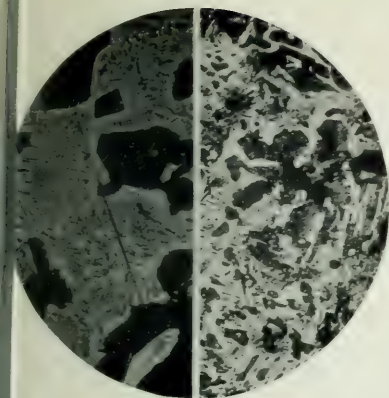


FIG. 5.—Gun-Metal in Vent.
Magnified 240 diam. Magnified 90 diam.

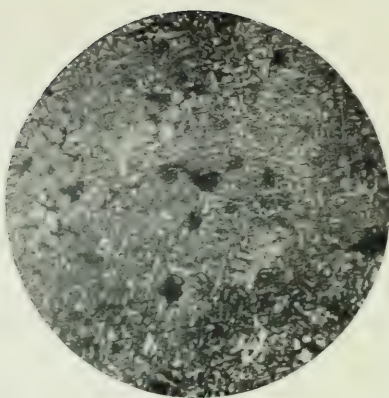


FIG. 6.—Gun-metal Test Bar.
Magnified 30 diameters.



FIG. 7.—Gun-metal Test Bar.
Magnified 30 diameters.

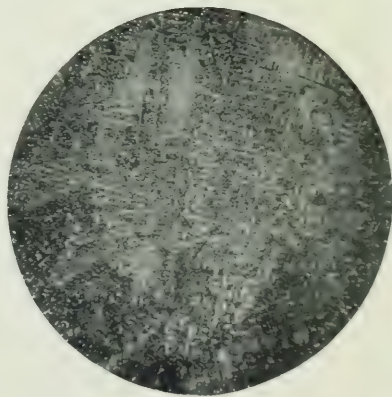


FIG. 8.—Gun-metal Test Bar.
Magnified 30 diameters.

PLATE XV

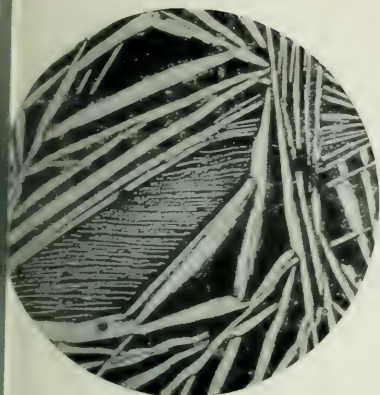


FIG. 9.—10 per Cent. Phosphor Tin.
Magnified 60 diameters.



FIG. 10.—10 per Cent. Phosphor Copper.
Magnified 90 diameters.

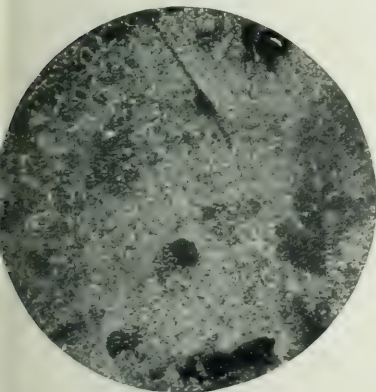


FIG. 11.—Gun-metal Test Bar.
Magnified 60 diameters.

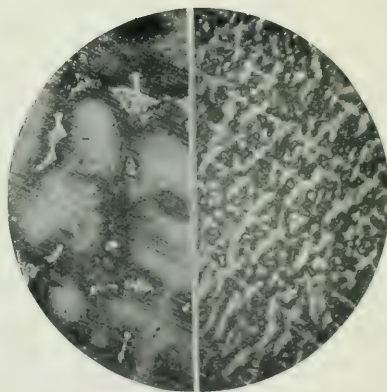


FIG. 12.—Gun-metal Test Bar.
Magnified 240 diam. Magnified 60 diam.

PLATE XVI

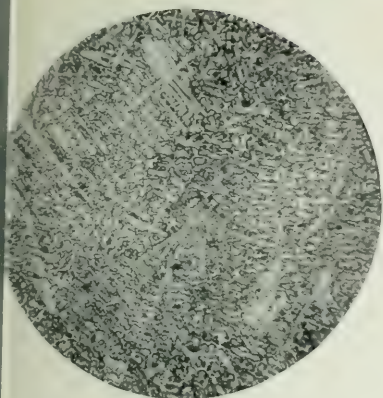


FIG. 13.—Bronze Casting.
Magnified 30 diameters.

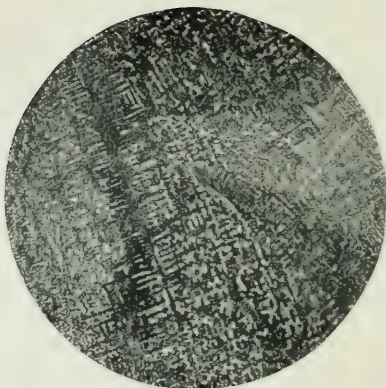


FIG. 14.—Gun-metal Test Bar.
Magnified 30 diameters.

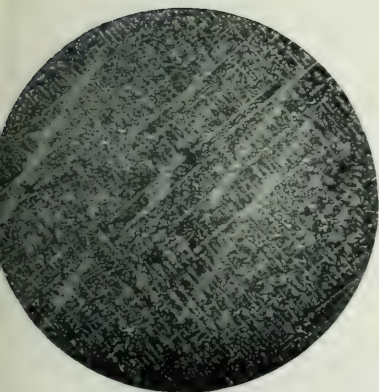


FIG. 15.—Gun-metal Test Bar.
Magnified 30 diameters.

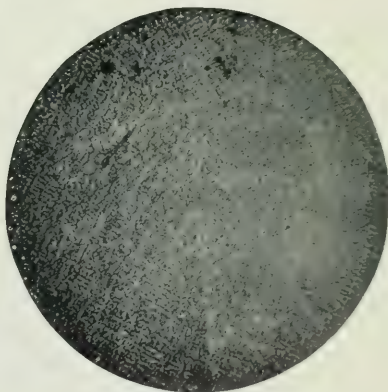
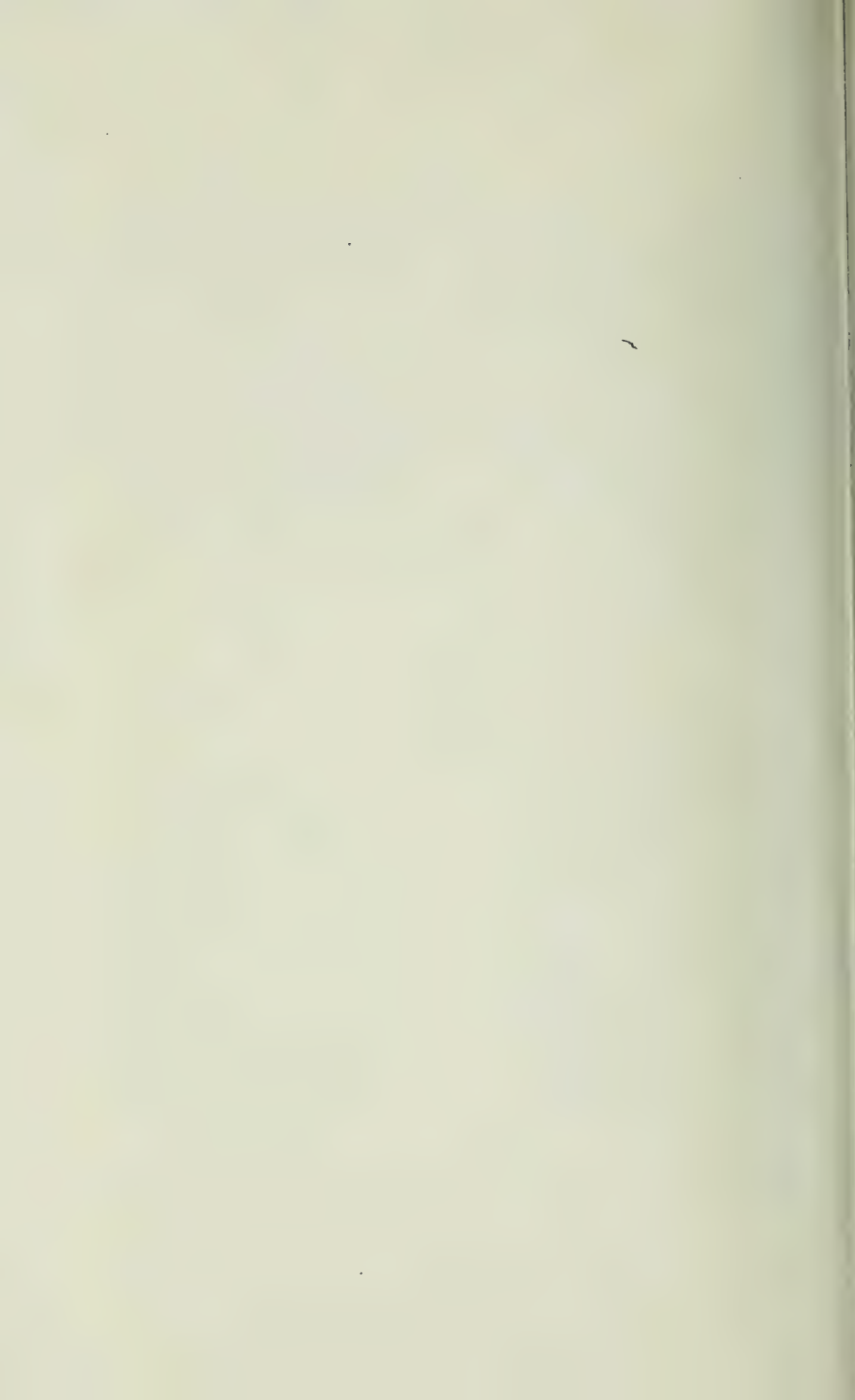


FIG. 16.—Gun-metal Test Bar.
Magnified 20 diameters.



JOINT-DISCUSSION.

Mr. G. A. BOEDDICKER, Member of Council, said that he welcomed Dr. Desch's contribution, which, on half a sheet of notepaper, practically contained the whole programme of the Institute of Metals, as an attempt at the classification of the "diseases" and "injuries" of metals. He did not, however, agree with Dr. Desch's classification, as he did not proceed on any definite lines; starting sometimes synthetically from the causes, and at other times analytically from the symptoms. Personally, he would prefer a strictly synthetical classification, and thought they might divide all faults into "medical" and "surgical" cases; the first comprising all those faults which could be traced by the chemist, and the other those which are caused by faulty physical treatment. The one would include faulty composition, cases of poisoning and diseases caused by oxygen and carbon; and the surgical cases would comprise injuries due to faulty heat-treatment and mechanical defects.

Dr. Desch asked that all specimens should be accompanied by as full a statement as possible of the exact conditions under which they were obtained. That unfortunately was a very difficult matter, as frequently defects showed many months after the metal was produced, and the use of pyrometers was still very limited.

In regard to sponginess, the statement that, "unlike other liquids, molten metals dissolve more gases as the temperature rises," could not be accepted without a great deal of doubt.

If it were generally true, mercury, for instance, which was in a state of considerable overheating, would contain a considerable amount of gases. His own impression was that at higher temperatures many molten metals evolved gases; in the case of copper alloys, for instance, by the action of the oxide contained in the metal on the graphite of the crucible. He found that in nickel alloys considerable overheating and violent stirring decreased sponginess, though unfortunately producing over-carbonisation, which made it inadvisable to overheat nickel alloys.

With reference to the remarks on allotropic changes, he thought that the change from combined carbon to graphite, occurring in nickel alloys by annealing at too high a temperature, was an example which was generally erroneously put down to burning. He thought the author's explanation of fire-cracks was correct. He had noticed, however, that the presence of oxides in the alloy—certainly in nickel alloys—tended to make fire-cracks more frequent.

He was very pleased to see a remark about Mr. Cohen's explanation of spontaneous crystallisation. He did not think, however, it was quite spontaneous, but caused by some vibration. He had a beautiful specimen of a German silver inkpot,* which, after being used in the tropics on board ship for about twelve months, developed a number of cracks, undoubtedly due to spontaneous crystallisation, which in this case very likely was started by the regular polishing to which this inkpot was

* [This inkpot is now in the Institute's Museum, thanks to the kindness of Mr. Boeddicker.—ED.]

subjected, unless the frequent changes of temperature in a journey to tropical climates had something to do with it.

He would like to congratulate Dr. Desch on his excellent book on "Metallography," which he thought should be in the hands of all members of the Institute of Metals.

Mr. F. JOHNSON, M.Sc. (Birmingham), said he would like to congratulate Dr. Desch and Mr. Primrose on their very useful papers. They would have an effect which Dr. Desch no doubt specially desired in the way of stimulating discussion. Dr. Desch had instanced bismuth in copper as a characteristic example of the brittleness caused by the presence of eutectic alloy between the crystals. From his own observations based on a study of the microstructure of copper containing small quantities of bismuth, he had found no evidence of eutectic structure. Copper and bismuth seemed to be entirely immiscible in the solid state, bismuth eventually solidifying as thin metallic envelopes, partitioning off crystal from crystal. The proportion of bismuth might, however, be so minute as to be insufficient to completely surround each crystal, in which case it would probably segregate at those points where several crystals met. Those metallic envelopes in section were entirely structureless when examined under the microscope at 1000 diameters. He would be glad if the author could tell them at what degree of concentration the eutectic first began to appear in its characteristic form. He thoroughly endorsed the remarks made concerning the difficulty of discerning minute quantities of insoluble impurities in such a soft tough metal as copper. Another great difficulty was the elimination of the last scratches from a polished specimen of copper. A polishing material which would remove those scratches so effectually that they would not be revealed by subsequent etching would be of great value to the metallographer. With regard to the presence of antimony in brass, there had been many wild statements made concerning its ill effects on the cold-working properties, one worker going so far as to say that 0.001 per cent. was sufficient to render brass unworkable. Mr. Sperry, in connection with the American Institute of Mining Engineers, conducted some experiments in 1898 with Muntz metal containing small quantities of antimony. He came to the conclusion that 0.02 per cent. was sufficient to alter the fracture of cast metal from fibrous to coarsely crystalline, and to seriously affect the cold working properties. Personally, he did not think that 0.10 per cent. was sufficient to have any such effects upon the appearance of the fracture. Certainly such an amount would not operate against the hot-working properties. The great danger lay in the coincident occurrence of arsenic and antimony. Neither element alone would have any very serious effects on the fracture or the hot-working properties up to 0.1 per cent., but, together, the total percentage sufficient to ruin the alloy would be very much below that figure. Many metallographers would recognise the truth of the author's remarks concerning the difficulty of discovering the conditions of strain in metals and alloys. He would like to have Dr. Desch's recommendations as to

the kind of physical test that should be applied for the recognition of those conditions.

Professor H. C. H. CARPENTER, M.A., Vice-President, said that they were under a special debt of gratitude to Dr. Desch for the paper which he had contributed in spite of his work as Hon. Secretary of the Local Committee. He could not help feeling sorry for the manufacturer, especially as Dr. Desch had by no means exhausted the list of what might be called "illnesses" that could befall metals. He would like to point out one or two further defects that could occur. First of all, on page 238, in regard to the sponginess of metal, Dr. Desch had referred to the dissolved gases as being the cause of that. That undoubtedly was one cause, but there were blow-holes which proceeded not from the dissolved gases, but from gases liberated from the mould, in alloys cast in sand, due to the sand being moist or too tightly rammed. This was a very prolific source of sponginess, as he happened to know. On page 243, Dr. Desch dealt with defects due to molecular changes. That was a very big field indeed. There were, *e.g.*, slow changes which occurred, particularly in copper-zinc and copper-tin alloys, leading to what was called the "crystallisation" of the material. He had had some experience of this in connection with castings of copper-tin alloys for hydraulic purposes, which suffered greatly from that particular defect. It was interesting to read of the new inversion of tin to which Dr. Desch referred, an inversion which took place above the ordinary temperature. His own experience had been with alloys which contained tin not as such but as a solid solution with copper. The important point was the big deterioration in quality which occurred with the lapse of time. A manufacturer might produce absolutely good material which would remain sound for a time, after which it deteriorated and was finally of no use. The cause of this was a slow molecular change from a metastable to a stable condition. He would pass by all the defects due to the pattern of the casting not being of the right shape. That was a great source of defect in various alloys. Then there were faults due to the crystallisation of metal in a particular direction with consequent weakness.

Mr. Primrose's paper was very useful. He noticed that on page 239 the author said that if the blow-holes were bright and clean and confined to the outer portion of the castings, they were certain to be due to the steam formed in the mould. That was an interesting difference from blow-holes formed in cast iron, where dull or oxidised blow-holes were invariably recognised as being due to the steam. He should like an assurance from Mr. Primrose on that point, that those blow-holes produced by steam were always bright.

Mr. H. H. A. GREER (Glasgow) said he had really taken part in the discussion because he felt there were so few Glasgow men present, whereas there ought to be quite a number. He must apologise for the small number who had attended. On the previous evening, when there were a lot of "good things" going, there were a large number of Glasgow men

present! They had among them only one or two manufacturers. He meant to tell the Glasgow men, as he moved about the city, what a number of interesting papers they had had, both of a theoretical and practical character, and he hoped that they would show their interest by joining the Society. The papers had been almost like the parson's sermon, the subjects having been ranged under various heads. They had had firstly, that which dealt with copper; and then secondly, relating to brass; and thirdly, that which dealt with gun-metal; and they had had the "finally, brethren, before we part," the summary of the whole put together in the paper of Dr. Desch. He wished to thank the two gentlemen for the very interesting papers they had read.

Mr. E. L. RHEAD, M.Sc. Tech. (Manchester), said he should like to join in thanking the authors for the valuable character of the papers. He should not have ventured to have addressed them again but for the fact that perhaps he could throw a little light on one of the defects which occurred in tin, and which was referred to by Dr. Desch. In his paper he did not state the nature of the tin which was the subject of the photographs, but he found from his remarks that it was a coil used for distilling, or a water condenser coil. It was well known to manufacturers of tin pipe that unless the temperature of expression was right the pipe was very brittle, so that any attempt to bend it would break it up into small rings, making it quite worthless for anything, and it had to go back to the melting pot. This condition was the result of the columnar structure assumed by the metal. It struck him that possibly the use to which the coil had been put caused it to be subjected to alternations of temperature, perhaps not very great, but while in the first place the pipe was sufficiently strong to bear bending, the alternating temperature led to further breaking up of the columnar structure and so caused it to fall to pieces. No doubt the cause was that breaking up of the columnar structure. Dr. Desch on page 244 referred to shrinkage cracks, and particularly to season cracks in brass and other alloys, which occurred during the working of the metal, converting what was otherwise *crystalline* material into *amorphous* material, and that the conversion was greater on the outer than upon the inner portion of the metal. He feared that on that matter he was a heretic, in not believing that a substance that had once assumed a crystalline condition could be reduced into an amorphous state, simply by being broken up into fine powder. The assumption of the crystalline form was due to some particular arrangement of the molecules of the substance, which led to the development of the specific form. Simple fracture, breaking up into any number of small parts, did not interfere with the physical characteristics that resulted from the crystalline arrangement, but simply produced disintegrated material. He should rather take the change to be the result of cleavages or fractures of the crystals in definite directions. These might extend or amalgamate to such an extent as to produce season cracks in time. He would suggest that the continuous fractures of the material were due to the fact that the metal having been

broken up was affected by ordinary changes, especially atmospheric changes, which were sufficient to extend and to amalgamate those cracks, and so reduce the density, and, in some cases, actually to produce definite separation by cracking. He would like to thank Mr. Primrose for the paper on metallography. There was one difficulty about metallographic work: it was that it was not recognised by manufacturers, or not adopted to a greater extent, owing to the belief that it was too difficult to carry out. He had tried to impress upon manufacturers that the preparation of specimens for metallographic examination was by no means difficult, and as Mr. Primrose had stated at the end of his paper, the use of the microscope was, that it enabled them to detect differences between good and bad material, and to some extent to indicate the nature of any fault. It was one of those applications of the microscope which could be very satisfactorily made, in any works where there was a man with a reasonable head on his shoulders, and who could apply what he had heard described the other day as "horse sense."

Sir WILLIAM WHITE, K.C.B., F.R.S., past-President, said there were two points in Dr. Desch's paper to which he might refer. On the last page of the paper corrosion and erosion were mentioned. In that Institute they were chiefly concerned with questions from the point of view of the composition and treatment of metals, but he thought that the remarks of Dr. Desch about erosion may have been associated with special conditions existing in the water, which produced that erosion. In the case of sea water set in motion by the action of high-speed propellers, Dr. Desch spoke of the action of eddies. It was quite true that there were eddies, and that subject was nearly related to phenomena which caused considerable trouble in connection with the efficiency of propellers, namely, the phenomena of cavitation. He had seen propellers which had been affected in the way Dr. Desch had described, and in some of these cases the blades were marked in a singular way which was also suggestive. It seemed notable that in many cases corrosion should occur on the faces of the blades, and it was possible that cavitation should occur on these faces, and that corrosion or erosion might be much increased in consequence. He had seen experiments in a tank where a great amount of power had been delivered to a propeller of which the thrust was actually made negative owing to the excess of cavitation on the driving face. This was a most interesting thing scientifically, but a most disappointing one practically. The propellers in that instance, of course, were of special design. In all probability certain compositions of metal would favour extensive corrosion, and the presence of free air in sea water might have a marked effect. In the old days, when they were using copper sheathing or Muntz's metal sheathing on the bottoms of ships, strange cases of corrosion occurred upon the surface of the metal sheathing; it was sometimes pin-holed by galvanic action, and in other cases very singular results occurred. In fact the possibility of variations in conditions were almost innumerable, and often it happened that the metal side of the question might become comparatively unimportant.

The Corrosion Committee of the Institute of Metals had his entire sympathy; but he ventured to suggest when the Committee was appointed that they should begin their work in dealing with some definite problem. That was the line on which the Committee should work. It was a very wide subject, and they hoped to know more about one section of it when the work of the Corrosion Committee became available. While he was in entire sympathy with the prosecution of inquiry, he was sure that the field of inquiry was so large that the Committee was quite likely to become a permanent or standing Committee of the Institute.

Dr. DESCH, replying on the discussion, said that he had to thank those gentlemen who had been good enough to speak on the subject of the paper, and he had taken very much interest in the points brought forward. In the first place, he had been much interested in what Mr. Boedlicker was able to tell them about nickel alloys, because the behaviour of the nickel alloys was of exceedingly great scientific interest, and differed in many respects from those materials with which most of them were more familiar, namely, the alloys of copper with zinc and tin. With regard to the overheating of nickel alloys, it was very interesting to hear the statement as to the escape of gases being facilitated when the metal was overheated. He had been asked for his reasons for the statement as to the solubility of gases. From measurements made recently with regard to the quantity of gas which could be dissolved by metals at temperatures above the melting point, it had been found in all cases that the amount of gas dissolved increased with the temperature, which did not occur when gases were dissolved in most other liquids. In some of those cases the gases would be given off in cooling, before the casting temperature was reached, and it was only in the case of rapid cooling that one would expect to get any super-saturated solution. Mr. Johnson had referred to page 239, where he had stated that a eutectic was formed as a brittle layer. There was in such cases as that mentioned no characteristic eutectic structure. The eutectic differed very little from pure bismuth, and the crystals of copper were separated by layers or films. A further question was asked as to what physical test would be recommended for determining the value of metals to be used at high temperature. The best test would be of the nature of an alternating stress test. Static tests were far less valuable. Mr. Rhead had raised the question of the behaviour of tin, and in that connection he (Dr. Desch) had referred to a tin condenser worm. He did not think in that case the defect arising was due to any defect in the manufacture of the worm, since on microscopical examination he had found the whole of it, with the exception of a few inches exposed to a higher temperature, perfectly normal. The new crystals were all formed perpendicularly to the surface of the metal.

Professor Carpenter had raised several very interesting points, more particularly with regard to the hydraulic castings crystallising after a long time. He supposed that those alloys had no cold work on them.

Professor CARPENTER replied in the negative.

Dr. DESCH, continuing, said that was a very remarkable change, which he imagined was not connected with the known molecular change in tin. Mr. Rhead had raised the question of season cracks in brass. He (Dr. Desch) had found it useful to adopt the view that Dr. Beilby had put forward as to the nature of the change undergone by strained metal. According to Dr. Beilby the change which took place was mainly a conversion of the crystals from stable material into amorphous material which behaved like glass. The behaviour of brasses showing season cracks or similar defects could be better understood on the assumption of the formation of an unstable material, of the nature of a greatly undercooled liquid, than by the assumption of innumerable fractures throughout the crystals. Coming next to the last page, he was very glad that Sir William White had been induced to say something on the subject of erosion, since no one could speak with such authority on the matter. In the speaker's references to erosion, he had been following the authority of a gentleman who had recently investigated cases of this kind. Dr. Silberrad, as the result of his experiment, came to the conclusion that galvanic corrosion played a small part in the erosion, which was almost entirely mechanical. That, however, was the result of a single research, and further investigation of these defects in high-speed propellers might lead to entirely different results. In conclusion, the speaker said he hoped some other gentlemen who had not contributed to the discussion might perhaps add something with regard to the classification of defects which had been suggested by other speakers, and in particular by Mr. Boeddicker.

Mr. PRIMROSE, in reply, said that with regard to Dr. Carpenter's remarks on the effect of steam on gun-metal, he held that when the holes were observed at the edge of the casting the effect was invariably due to steam in the mould. These were recognisable from oxide inclusions from the fact that the latter polished out irregularly, but the holes from steam or gas were clean. Steam was unable to oxidise gun-metal, as it did iron; thus a marked difference in the appearance of the holes left was noticeable under the microscope.

COMMUNICATION.

Mr. C. O. BANNISTER, Assoc. R.S.M. (London), wrote that he considered Dr. Desch's paper of very great interest and value. It would, no doubt, prove most useful for reference as a first approximation to a classification of the diseases to which the non-ferrous metals and their alloys were subject. It should also have a great influence in showing the more technical members the great value of metallographic methods of examination to both producers and users of these materials. The author had rightly omitted from his classification those alloys which proved defective owing to unsuitable composition, for the control of the

composition should in general be the work of a chemist; yet, strictly speaking, the thin layers of eutectic alloy sometimes present between the crystals, producing discontinuity and brittleness, were due in the first place to the unsuitable composition of the materials used for making the alloys. There were, however, certain cases of unsuitable composition beyond the control of the chemist, such as the accidental admission of extraneous matter into the mixture for melting. The writer had examined certain defective alloys in which the trouble had been caused by the inclusion in the mixture of particles of metal which did not alloy with the main bulk, and were found here and there in the finished or partly finished article, for example, distinct pieces of steel in brass. The detection of gas-pores, oxides, dross, and intercrystalline eutectics was likely to prove one of the most permanent uses to which the microscope would be put in the control of commercial metals and alloys. The study of segregation in its many aspects was also materially assisted by means of the microscope, but the macroscopic examination of large sections has not yet received the careful study and attention it deserved. With regard to the "burning" of alloys, the writer considered that it was a misfortune that that term was used with so many meanings; in some cases it was used to indicate merely a coarse crystalline structure, in others to indicate the segregation of one of the constituents to the crystal boundaries; it was also applied to the loss of one of the component metals by volatilisation, and lastly, to actual oxidation due to heating to an excessive temperature in an oxidising atmosphere.

It would appear that the last interpretation only should be used, and that other suitable terms should be found for excessive crystalline growth, segregation between crystals and loss by volatilisation during annealing. On referring to the original definition of "burnt brass" in the paper by Messrs. Bengough and Hudson, and also to the modified definition given by Mr. Bengough on introducing the paper, it would be found that there was no indication that actual burning or oxidation need have taken place, and that the lowering of ductility or the unusual susceptibility to cracking might possibly have been due to other causes.

STATUTORY MEETING.

A GENERAL OR STATUTORY MEETING OF THE INSTITUTE OF METALS was held at the Institution of Mechanical Engineers, Storey's Gate, Westminster, S.W., on Tuesday, October 11, 1910, Sir GERARD MUNTZ, Bart., President, occupying the Chair.

The SECRETARY read the notice convening the Meeting.

The PRESIDENT stated that the Meeting was purely a formal one, and was held to comply with the Companies (Consolidation) Act, 1908, on account of the fact of the Incorporation of the Institute, which took place on September 10, 1910.

COUNCIL FOR 1911.

The SECRETARY read the following list of members nominated by the Council to be balloted for in connection with the election of the Council for 1911, the result of the ballot to be declared at the Annual General Meeting, to be held at the Institution of Mechanical Engineers, Storey's Gate, Westminster, on January 18, 1911, this list having been prepared by the Council in accordance with the Articles of Association, Section III. 16.

President.

Sir GERARD A. MUNTZ, Bart.

Vice-Presidents.

(Two to be elected.)

Professor H. C. H. CARPENTER, M.A., Ph.D.	.	Manchester.
Professor W. GOWLAND, F.R.S.	.	London.

Members of Council.

(Eight to be elected.)

*Mr. LEONARD ARCHBUTT	Derby.
†Professor ARCHIBALD BARR, D.Sc.	Glasgow.
†Dr. G. T. BEILBY, LL.D., F.R.S.	Glasgow.
†Mr. G. A. BOEDDICKER	Birmingham.
†Mr. J. CORFIELD	Swansea.
*Mr. GEORGE HUGHES	Horwich.
†Mr. EDWARD MILLS	Swansea.
†Mr. G. H. NISBETT	Prescot.
†Mr. E. RISTORI	London.
*Dr. WALTER ROSENHAIN, D.Sc.	London.

* New nomination.

† Re-nominated in accordance with Articles, Section III. 18.

‡ Retires in accordance with Articles, Section III. 15, and re-nominated.

The PRESIDENT reminded the Meeting that, in accordance with the Articles, Section III. 16. any ten members may also at the Meeting nominate a candidate other than one of those nominated by the Council, but none of the members present exercised their right in this matter.

The proceedings then terminated.

BIRMINGHAM LOCAL SECTION.

THE FIRST MEETING OF THE BIRMINGHAM LOCAL SECTION OF THE INSTITUTE OF METALS was held in the University of Birmingham on Tuesday, November 22, 1910, Mr. G. A. BOEDDICKER (Chairman of the Section) presiding over an attendance of eighty Members of the Section and their friends.

The CHAIRMAN said that it was a great pleasure to him to see so many friends of the Institute of Metals present at that, the first, Meeting of the Birmingham Local Section. Their presence showed that they appreciated the good work that the Institute was doing, but as yet not every one had been quite satisfied. Complaints had been made that many of the papers presented at the Meetings of the parent Institute had been too scientific. He (the Chairman) held that such a complaint could be dealt with in one of two ways: either by lowering the standard of the papers, or by raising the standard of the members. It was needless for him to say that, as citizens of Birmingham whose motto was "Forward," they could accept only the latter course. He had come into contact with a large number of people interested in metals, amongst them being mechanical and electrical engineers; chemists; metallurgists; practical and commercial men. Generally speaking, he had found that every one besides knowing his own branch perfectly had a very fair knowledge of every other science which might be applied in the treatment of metals, with the one exception of "Metallography." What that science had done for the steel industry was almost ancient history, but its application to non-ferrous metals and alloys was of rather recent date. It had done a great deal of good already, and would do greater things in the future. A new science always had to invent a new language, and the reason why papers dealing with metallography had not met with full appreciation and had not aroused the interest they deserved had been that many of the members were not familiar with the particular

language of that science. With a view to remedying that defect he (Mr. Boeddicker) had induced Mr. O. F. Hudson, M.Sc., to present to the members of the Birmingham Section two papers as an introduction to the science of metallography, and he felt sure that these papers would enable every member who listened to them intelligently to appreciate future metallographical papers that were read at the General Meetings of the parent Institute. Another point that had been raised was that the Institute did not have enough practical papers. In his opinion it was not easy to have practical papers read and discussed at General Meetings, and he had advocated from the very first the formation of Local Sections whose meetings were the proper places for the presentation of practical papers and for the discussion of practical questions. With regard to the future, he had pleasure in stating that, in addition to the papers by Mr. Hudson, two other papers would be presented to the Section during the present session: one on "Rolling-mill and Tube-mill Practice in America," and another on "Annealing and Annealing Furnaces," both of these being papers that could not fail to be of the greatest interest to all members of the Institute in Birmingham and district.

Mr. O. F. HUDSON, M.Sc., Special Lecturer in Metallography in the University of Birmingham, then delivered the first portion of his paper on "An Introduction to Metallography." In his paper, which was illustrated with lantern slides and a number of micrographs of alloys of copper, tin and lead, antimony, &c., the Lecturer gave an interesting résumé of the advancement of metallography as a science, of which Dr. Sorby of Sheffield might be said to be the founder. Mr. Hudson described the development and significance of the crystalline structure of metals, tracing the freezing processes, and interpreting the appearances exhibited on the screen. He showed how it had been possible entirely to alter the character of certain non-ferrous metals and their alloys by controlling the thermal changes.

At the conclusion of the reading of the paper a vote of thanks to Mr. Hudson was proposed by the Chairman, and was passed by acclamation. The members of the Section

were invited to send by post to Mr. Hudson questions relating to the subject under discussion, these to be answered at the next meeting. They were also asked to bring specimens of metals and alloys regarding the working, or use, of which difficulties had arisen.

THE FORMATION OF LOCAL SECTIONS.

The establishment of the first Local Section of the Institute is a matter of such general interest to members that it is felt desirable to place on record a few facts regarding the origin and development of the Birmingham Local Section.

At a meeting of the Council held in London on April 27, Rules were drawn up, at the suggestion of Mr. G. A. Boeddicker, for the governance of any Local Sections of the Institute that might be formed. Powers for the formation of such Sections had been taken in the new Memorandum and Articles of Association which had been adopted at the Annual General Meeting held in London on January 18, 1910. These Rules are as follows:—

- (1) The Council may, at their discretion, upon receipt of a request to that effect from a sufficient number of Honorary Members, Fellows, Members, Foreign Members, and Students, resident in any district, create a Local Section of the Institute in such district, and they shall also have power to dissolve such Section at any time after it has been formed.
- (2) Local Sections shall be managed by a Local Committee, and at least one member of such committee must be a member of the Council.
- (3) The Committee of a Local Section must prepare Rules for the government of the Section, which Rules have to be submitted to the Council for sanction.
- (4) The Local Section shall not be a charge on the funds of the Institute, nor is the Institute responsible for any liability incurred by such Section.
- (5) Full reports of any Meeting held by a Local Section, and a copy of all Papers read thereat, shall be sent to the General Secretary, and the Council shall have the right to publish in the Journal any Papers or reports of Meetings on the recommendation of the Publication Committee.
- (6) Every Member may invite visitors to attend Meetings of the Local Sections, but no visitor shall be permitted to attend more than one Meeting per annum, except at the invitation

of the Local Committee, provided also that any individual being eligible for membership of the Institute, and nominated from a Local Section, may be admitted to the Meetings until such time as his name comes before a General Meeting for election.

On 10th June a circular letter, signed by Mr. G. A. Boeddicker and Mr. G. G. Poppleton, was issued to all members of the Institute resident in the Midlands, informing them that as the establishment of Local Sections had been sanctioned by the Council, they were invited to attend a meeting to be held on 16th June to consider the advisability of forming a Local Section for Birmingham and District. This meeting was duly held at the Grand Hotel, and was attended by about twenty members, who signed a request, which was in due course forwarded to the Council, asking the Council to agree to the formation of a Local Section of the Institute for Birmingham and District. A Committee was appointed to prepare Rules and submit these to a further meeting to be held on July 4, 1910. This meeting duly took place, and draft Rules were approved. The Council having previously agreed to the formation of the Section, these Rules were submitted to the Council and approved. The various preliminary details having thus been satisfactorily arranged, the Local Committee proceeded to draw up a programme of meetings for the Local Section, some details of which have been given above. The officers of the Section who were appointed at the meeting held on July 4, 1910, are as follows:—

Chairman.

Mr. G. A. BOEDDICKER, Henry Wiggin & Co., Ltd.,
Wiggin Street, Birmingham.

Joint Hon. Secretaries.

Mr. R. M. SHEPPARD, French Walls, Birmingham.
Mr. G. G. POPPLETON, 26 Corporation Street, Birmingham.

Treasurer.

Mr. F. JOHNSON, M.Sc., 428 Gillott Road, Birmingham.

Members of Committee.

Messrs. J. W. EARLE.	Messrs. E. W. DOBBS.
„ O. F. HUDSON, M.Sc.	„ B. J. MASON.
„ VAUGHAN HUGHES,	„ A. SPITTLE.
Assoc. R.S.M.	Professor TURNER, M.Sc.

SECTION II.

ABSTRACTS OF PAPERS

RELATING TO THE NON-FERROUS METALS AND THE INDUSTRIES CONNECTED THEREWITH.

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ORES AND MINERALS.

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I.—OCCURRENCE.

Gold in Mexico.—E. A. H. Tays* describes the gold resources of San José de Gracia. The district was first explored by missionaries in 1630, and ten years later gold was found there, but only intermittently and precariously. In 1828, however, a rich quartz ledge was discovered, and the Mina Grande was thus started. Other finds with rich surface bonanzas soon followed. The camp of San José de Gracia is in the north-east of Sinaloa, Mexico, and almost on the boundary line of the State of Sinaloa and that of Chihuahua. The formation is andesite and rhyolite, but much faulting has taken place.

Gold Mining in Durango.—W. B. Beverly† gives an account of early mining in Durango, and contrasts the methods in vogue in 1886 with those now practised. Details are given of the costs of supplies, wages, and mining and smelting.

Iron Ore in Mexico.—The iron ore resources and the geological configuration at the Pamilla Mine, Mexico, are described by F. W. Smith.‡ The ore occurs in fissures and fracture zones in a large intrusion of andesite in shale. It is chiefly porphyry, the best grade containing 67 ounces of silver and 0.70 ounce of gold, and some bunches and stringers of ore reaching as much as 10 to 15 ounces of gold. The ore bodies dip steeply, the strike of the vein being north 5° to 20° west, while at some levels the shearings dip easterly 50° to 75°.

Minerals of Cobalt District.—An article is given by A. A. Cole§ on the geological, mining, and economic condition of the cobalt region. The silver deposits of cobalt are in pre-Cambrian rocks, most of the

* *Engineering and Mining Journal*, vol. lxxxviii. pp. 640-645.

† *Ibid.*, vol. lxxxviii. pp. 635-639. ‡ *Ibid.*, vol. xc. pp. 259, 262.

§ *Engineering Magazine*, October 1910, vol. xl. pp. 15-30.

most valuable ones in Huronian conglomerate, and a few in Keewatin greenstones and post-Huronian diabase. The deposits are probably genetically connected with masses of the diabase, with which they are always closely associated. The veins are nearly perpendicular and are narrow. The vein-filling is usually calcite carrying native silver associated with arsenides of nickel and cobalt in varying amounts. The article contains details of concentration methods used.

Zinc and Lead Ores in Arkansas.—The development of the Arkansas mineral region is discussed by L. L. Wittich.* The ores in this district occur chiefly in the Yellville formation of the Ordovician system. The Yellville formation is composed of magnesian limestones or dolomites. The Key sandstone is a valuable guide to the miner. It is found in benches, and often marks the cap rock overlying the dolomites in which the ore occurs. Fracturing, jointing, faulting, and slight brecciation characterise the areas where the mineral is most likely to be encountered. The ore, when a blende, is of a high grade. The Key sandstone is easily recognised by its resemblance to light-brown sugar and by its being easily pulverised. The general tendency of Arkansas operators seems to be to abandon tunnelling and use shaft sinking instead.

II.—MECHANICAL PREPARATION.

Development of Heavy Gravitation Stamps.—W. A. Caldecott † traces the development of crusher stamping from the earliest times to the present day, and shows the reasons which have led to the adoption of heavy gravitation stamps in gold quartz crushing operations on the Rand, where, of late, stamps weighing as much as 1500 lbs. have been installed, with successful results.

Economics of Gold Mining.—An account of comparative methods of working and of the relative costs at mines on the Witwatersrand has appeared.‡

Electrostatic Ore Separation.—An article§ is devoted to the principles of electrostatic ore separation, and incidentally the Huff machine is mentioned. Ores for electrostatic separation must be dry and preferably free from dust. Fine crushing is not necessary, nor is fine sizing, though coarse sizing is usually advisable. Minerals may be divided into two classes—good and poor conductors.

Minerals of the one class may be separated from those of the other, and in many cases minerals of the same class may be separated. If two

* *Mines and Minerals*, August 1910, vol. xxxi, pp. 15-30.

† *Engineering and Mining Journal*, vol. lxxxviii, pp. 594-598.

‡ *Ibid.*, p. 593.

§ *Metallurgical and Chemical Engineering*, May 1910, vol. viii, pp. 295-296.

minerals cannot be separated in the natural state, the conductivity of one may be altered by artificial means, such as by heat or by chemical or electro-chemical action. The following is a general classification of the common minerals according to their conductivity:—

Good Conductors.—Most sulphides, such as pyrite, galena, chalcopyrite, and chalcocite. Native metals, such as gold and copper. Some oxides, such as magnetite and hematite. Certain arsenic and antimony compounds of copper and silver, such as pyrargyrite and tetrahedrite, biotite, graphite.

Poor Conductors.—Most silicious minerals and rocks. Most carbonates. Most sulphates. Zinc sulphide.

Elements of Slime Concentration.—The progress of concentration methods is considered by W. McDermott,* who gives the following as the chief types of concentrating machines: (1) Fixed inclined tables; (2) jerking tables; (3) shaking travelling belts; (4) jerking or bumping travelling belts; (5) shaking side-inclined belts or tables.

The principle on which each type depends for success is considered, and the conditions affecting efficiency are dealt with.

The vanning shovel is considered as the simplest and most perfect appliance in use, and the conditions essential to good work, irrespective of the skill of the operator, are stated to be: (a) Sufficient time for settling; (b) a smooth surface for final separation; (c) a gentle movement of the washing water; (d) a motion to assist in differential settling and in separation. These elements are examined in detail as to their application to the construction and operation of concentrators of various kinds.

The direction in which improvements may be expected are next considered, and it is suggested that new concentrators which require serious consideration will probably be modifications of established types in which there must be a large and smooth surface; a regular settling motion which does not jar the finest particles from their contact with the surface when settled; and a delivery of clean mineral without the production of a middle class.

The necessity for classification before concentration is very marked in some cases with some machines, but actual experience has shown that in certain cases it is undesirable and in other cases is so imperfectly applied as to largely neutralise its advantages.

Miami Concentrating Mill.—A description of the concentrating mill now in course of construction at Miami is given by R. L. Herrick.† This mill embodies the best constructive features of previously built copper concentrating mills, and is built on a steep hill, by which means head-room is obtained in the mill and a tailings dump in the gulches below. There are four floor levels to the main mill building, the uppermost being for the screens and fine rolls, the next floor for the

* *Bulletin of the Institution of Mining and Metallurgy*, April 1910, No. 67.

† *Mines and Minerals*, August 1910, vol. xxxi. pp. 1-3.

Chilian mills, the next floor will carry the classifiers and concentrating tables, and the lowest floor will be used for the settling tanks and slime tables.

A special feature of importance is the absence of elevators, the nearest approach to this kind of machinery being one inclined conveyer belt and several small centrifugal pumps. The flow of ore and pulp through the plant with these exceptions is accomplished by gravity.

A description is given of the proposed method of treatment in which provision is made for the accurate classification and uniform sizing of the pulp grains fed to every concentrating and slime table, thus ensuring the early elimination of barren tailing and reducing the re-treatment of middling to a minimum.

By providing adequate capacity of settling tanks, every concentrator is fed with a pulp sufficiently thickened to ensure the best results. From experimental mill tests it seems likely that the extraction will be between 75 and 80 per cent., and from an ore averaging 2.75 per cent. copper a concentrate is expected to contain about 40 per cent. copper.

New Dry Ore Concentrator.—A new dry ore concentrator has been developed by the McKesson Concentrator Company of Colorado Springs.* It is of steel construction throughout, with the exception of the belt, which is of some suitable cloth fabric.

The machine is 5 feet long, 4 feet wide, and 5 feet high, and requires a floor space of 6 by 6 feet. Supported on the steel frame is a fan and a triangular box into which an air current is forced. Ore is fed through an adjustable automatic feeding device at the upper edge of the belt and forms a thin bed on it. The fan, revolving at 2100 revolutions per minute, delivers a current of air into the air chamber beneath the concentrating surface.

The air is forced through the pores of the belt in innumerable jets and produces a stratification of the particles forming the bed of ore, forcing the lightest to the top. A series of iron bar launders are fixed, and between these adjustable cross-riffls are supported. These launders direct the flow of the upper lighter strata of the bed of ore towards the tailings discharge, and the cross-riffls may be depressed at points below the launders, pressing the belt away from the launders and allowing the settled concentrate to pass with the belt to the concentrate delivery. By depressing the cross-riffls at the proper points, different minerals, such as galena and pyrite, can be withdrawn as separate concentrates. Just as the concentrate is about to be delivered, provision is made to clean it with air coming up at the edge of the air chamber. Various materials are used for the belt. For dry slime, a satin belt has been found best; for fine ore, a sateen belt; and for coarse ore, a twill or light canvas. Results of tests on a Leadville zinc-lead iron sulphide ore are given.

Zinc Ore Dressing in Colorado.—A description is given of the methods adopted for the dressing of the ores of the Marion Mines by

* *Metallurgical and Chemical Engineering*, September 1910, vol. viii, pp. 549-550.

H. C. Parmelee,* which is an interesting example of the development of economical ore dressing in spite of the disadvantage of a 26-mile wagon-haul for concentrates.

The mineralised fissure occurs in granite, and is composed of schist and altered granite, with sulphides of zinc, lead, and copper. The zinc content varies from 12 to 22 per cent. Cheap water power has been provided for all milling operations. The Marion ore lends itself quite readily to a system of wet concentration which has been adopted after testing the efficiency of several other methods. The mineral particles in the ore are small and quite finely disseminated throughout the gangue necessitating fine grinding. The crushing involves the use of crushers, rolls, and tube mills, and the product is delivered to Callow thickening cones preparatory to classification. The pulp is classified by a Richard pulsator classifier, and the concentration is carried out on Card tables. The table products are (1) lead concentrate, (2) zinc concentrate, (3) zinc middling, (4) tailing, and (5) slime. The first is very small in quantity, but carries most of the gold and silver in the ore; the zinc concentrate averages 40 per cent. of zinc, the middling assays about 15 per cent. of zinc, and is re-treated. Details are given of screen analyses of tube mill work, and also of the pulsator classifier work.

III.—METALLURGICAL PREPARATION.

Sintering of Fine Ores.—The chief processes for sintering fine ores of lead and copper are briefly described by A. B. Young† in a paper read before the Fifth General Meeting of the Western Association of Technical Chemists and Metallurgists. With regard to copper fines, the future of sintering as an economic method depends chiefly on the cost of operation plus the cost of smelting in the blast-furnace as compared with the cost of roasting in the ordinary way plus the cost of smelting in a reverberatory; and, secondly, the cost of ordinary smelting plus briquetting as compared with the cost of sintering. The author considers the operation of sintering in pots intermittently to be crude, for it is a waste of capacity for the sintered layers to be dormant in the bottom of a pot waiting for those above to be treated in the operation; it is a waste of power having to drive air at a high pressure through the charge, and the handling of large lumps of sinter is a clumsy and expensive operation. The solution of the problem lies in the development of a continuous sintering machine, taking and discharging the sintered material in thin layers, and the author describes a sintering machine he has designed, in which he has applied the endless-belt principle and erected partitions on the bars of the travelling grate dividing it into compartments, thus

* *Metallurgical and Chemical Engineering*, October 1910, vol. viii. pp. 568-570.

† *Ibid.*, May 1910, vol. viii. pp. 260-262.

dividing the sinter into blocks of suitable size. This machine consists of a grate in the form of an endless travelling belt which carries a bed of fines and passes for nearly its entire length over a suction or wind box by which air is drawn through the mass. Means are provided at one end for distributing the layer of fine material over the surface of the grate and for its ignition, and at the other end the sintered product is discharged into a convenient receptacle.

EXTRACTION OF METALS.

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I.—COPPER.

Basic Lined Converters for Leady Copper Mattes.—According to R. R. Moore,* treating lead-copper mattes in the converter has often been found to lead to enormous losses in silver, reaching, according to Peters, the “preposterous” amount of 50 per cent. The losses can be greatly reduced by careful operation and the filtration of the fumes through woollen bags. At Perth Amboy the bag-house flue dust contained less than 6 ounces of silver per ton, and 50 per cent. of lead. Without a bag-house great losses of copper and associated metals may occur. At Perth Amboy much trouble was encountered at first with the bag-house, and the cotton bags first used had to be discarded in favour of woollen bags.

Blast-Furnaces in Mexico.—New copper blast-furnaces at Teziutlan, Mexico, are described by C. Robinson.† They are the outcome of a design worked out at El Paso. Over each furnace is located a 65-ton bin, the charge car running directly over the top of these bins, which have five dividing plates, cutting each bin into five sections. Each such compartment has two gates each operated by a hydraulic cylinder, and all ten cylinders are controlled from one bank of levers. There are ten points, therefore, from which a furnace can be fed from a bin, which gives practically the same control as feeding by shovel, and great uniformity can be secured. Illustrations of the plant and diagrams of the furnaces are given.

Circular Copper Blast-Furnaces.—A comparison is made of the forms of furnaces used for smelting iron and copper ores by T. E. Lambert.‡ It is first pointed out that in the process known as pyritic

* *Engineering and Mining Journal*, vol. xc. p. 263.

† *Ibid.*, vol. lxxxviii. pp. 655–657.

‡ *Mines and Minerals*, August 1910, vol. xxxi. pp. 20–23.

smelting, the constituents of sulphide ores provide almost sufficient fuel for their reduction, thereby reducing the cost of smelting and also eliminating costs of concentration, roasting, &c. The author considers that in the early stages of the manufacture of pig iron the operations were practically identical with those for the production of copper, but means were devised for its more extensive and economic production. At present the smelting of copper is in about the same state as iron smelting between the years 1850 and 1870. Details are given of the Anaconda Copper Company's Washoe plant, which is compared with a modern iron blast-furnace plant. The author considers that the Washoe furnaces, which are of abnormal length, do not show increased quantity of ore smelted in proportion to length or other advantages over the types in general use, but that increased length results in greater loss of heat and waste of blast. It is inferred that as soon as a circular or square shape of furnace is departed from, and with a low smelting column, there cannot be the same equality in the condition of the materials composing the charge, nor can there be such an even distribution and utilisation of the blast to secure the necessary temperatures to effect the various reactions. When a long rectangular furnace is supplied with an unlimited quantity of blast, it will necessarily smelt more ore than one half its length, but this may not prove the more economical practice, as much depends on the methods of preparing the charge, charging, amount of blast, and amount smelted per square foot of hearth area. Examples are given of the working of different furnaces which tend to prove that better results are attained by the employment of shorter furnaces. The use of hot blast is discussed and its advantages in iron furnaces are stated; but with regard to the use of hot blast in copper smelting there are differences of opinion. It has been experimented with and abandoned, but this should not condemn its use with different furnaces. The trouble heretofore consisted in the use of rectangular furnaces with low smelting columns, but should the furnaces be of the same shape and dimensions as those used in smelting iron ores, it is probable that hot blast would be advantageous.

Copper Smelting at Trail.—A description of the equipment and methods of smelting copper at Trail is given by J. M. Turnbull.* There are five copper furnaces of the following sizes: Two 42 inches by 240 inches, two 42 inches by 300 inches, and one 42 inches by 263 inches at the tuyeres. The height of the charge is 9 feet above the tuyeres, and an air pressure of 36 ounces is used. Each furnace has a track on either side on which the charge trains are alternately run. Two fore-hearths are used, the second catching only 0.25 to 0.5 per cent. of the total matte. The practice at present is to smelt the ores which average 1 to 1.3 per cent. copper and 9 to 12 dollars per ton in gold, to a low-grade first matte which carries about 15 per cent. copper. The slag produced averages about 43–46 per cent. silica, 14–15 per cent. ferrous oxide, 20–22 per cent. lime, 0.1 per cent. copper, with trifling amounts of

* *Mines and Minerals*, September 1910, vol. xxxi. pp. 121–123.

gold and silver. The low-grade matte, containing 15 per cent. copper, 27 per cent. sulphur, and 56 per cent. iron, is roasted to about 10–12 per cent. sulphur, then blown in lead converters to a product containing 1–3 per cent. sulphur. The roasted matte is smelted to a high-grade matte running about 40 per cent. copper, which is shipped for further treatment, no copper converters being as yet installed. The high-grade slag runs about 40–42 per cent. silica, 26–28 per cent. ferrous oxide, 16–18 per cent. lime, 10–12 per cent. alumina, with 0.35 per cent. copper and 0.2 ounce of gold per ton. [See also Lead Smelting and Refining at Trail, p. 285.]

Extraction of Copper from Pyrites Cinders.—The methods used for the extraction of copper from cuprous pyrites cinders are reviewed by S. Lilja,* who gives a brief account of the history of the subject, and then discusses the most advantageous location of a chloridising plant. The process is divided into the following operations, each of which is described in detail:—

- I. Mixing with salt and the crushing of the mixture.
- II. Roasting proper.
- III. Leaching.
- IV. Precipitation of silver.
- V. Precipitation of copper.

I. As a general rule 12–15 per cent. of salt is added to the burnt residues and some green ore if necessary. The fineness of grinding depends on the nature of the residues, and usually an 8 to 12 mesh is used.

II. Under this head the various forms of roasting furnaces are described. These include kilns, muffles, and mechanical roasters.

III. A convenient arrangement of the leaching department is given, with some details as to the construction of the leaching vats. The time of leaching is usually forty hours for a 10-ton charge. Of the copper in the roasted ore about 80 per cent. is soluble in water, 16 per cent. is soluble in weak hydrochloric acid, and 4 per cent. remains in the purple ore.

IV. For the precipitation of the silver, Claudet's process is most common, in which zinc iodide or sodium iodide are used as precipitants. The silver iodide is reduced by zinc and sulphuric acid, but sometimes sodium sulphide is used which reacts with the silver iodide, forming silver sulphide and regenerating sodium iodide which is used again.

V. For the precipitation of the copper scrap iron is used.

The final product of purple ore may be converted into lump form by some sintering process before it is used in the blast-furnace. For this purpose in the nodulising method the residue is passed through a long rotary cylinder in which it is heated to a high temperature by means of powdered coal blown in at the discharge end. The product varies in size from that of rice to that of walnuts, and forms hard balls more or less

* *Metallurgical and Chemical Engineering*, July 1910, vol. viii. pp. 395–399.

thoroughly sintered. By the Gröndal method, the cinder is formed into briquettes of uniform size by an automatic plunger press. The briquettes are loaded on flat cars, which are slowly pushed through a channel kiln 150 feet to 200 feet long. Here they are gradually heated until they arrive at a zone of the kiln where the temperature is 2400° F. As fuel, producer gas is usually employed, and the finished product is hard and strong but porous.

Portable Copper Smelting Furnace.—P. A. Babb* describes a new hot-blast furnace for small smelting operations, the novel feature of which is the mode of delivering blast, as the tuyeres have been entirely dispensed with. In their stead there is a continuous opening of an inch or two in height, forming the blast way into the stack, and located between the crucible and the stack. By these means all chilling of slag is avoided, so that a “freeze down” cannot occur, and so hamper operations, as is frequently the case in ordinary tuyere furnaces. The crucibles can be quickly changed. The furnace is specially suitable for use in countries such as Mexico, as it is built for rough mountain transportation, and is cheap and effective. Details of test runs on rich ores are given.

Sectional Pot for Copper Slags.—It is pointed out by E. C. Reeder† that with large slag pots there is always more or less trouble with the bowls of the pots cracking. At the works of the Canadian Copper Company, 20-ton pots are used. These were originally made of cast iron, but after a comparatively short service went to pieces. Cast steel was afterwards tried with great improvement, but finally a scheme was adopted to make the pot sectional, and this has worked very successfully. The bowl is made in five pieces. In actual use the top sections crack first, but it is a simple matter to replace the broken part.

Yampa Smelter at Bingham.—A description of the methods in use at the Yampa smelter is given by L. A. Palmer.‡ This smelter is concentrating the lowest-grade copper ore in the country, and the resultant matte is the lowest in copper content of any of the smelters now in operation. An average of the ore during a recent month shows: Copper, 1.92 per cent.; iron, 27.9 per cent.; lime, 3.1 per cent.; alumina, 6 per cent., with very small quantities of gold and silver. The method of crushing and sampling is fully described. The roaster building contains nine 8-foot McDougall roasting furnaces. Each furnace has six hearths with water-cooled rabbling arms, except the two upper hearths, where the heat is low and the water is not needed. One and a quarter hours is occupied in working the charge through the roasters. The roasted ore is conveyed to reverberatory furnaces, a drawing of which is given. There are three of these furnaces, 17 feet wide, 47, 53, and 59 feet long respectively, with a smelting capacity of 150–175 tons

* *Engineering and Mining Journal*, October 2, vol. lxxxviii. pp. 647–650.

† *Mines and Minerals*, October 1910, vol. xxxi. p. 149.

‡ *Ibid.*, August 1910, vol. xxxi. pp. 14–18.

of ore per day. The fire-boxes are 9 feet by 12 feet, divided into two compartments by a brick wall. The fuel is fed from the roof, and draught for the fire-boxes supplied by a centrifugal blower. Between each furnace and the stack is a 300 horse-power water-tube boiler, utilising the waste heat to generate steam at 110 lbs. pressure. No dust chambers are provided for the reverberatory furnaces. The boilers are cleaned about every fifty days, and only 1 ton of dust is found to accumulate in this time. These furnaces used 5 cwt. of coal per ton of ore smelted. The matte is tapped once a shift and sometimes not so often. The slag is skimmed two or three times a shift. The matte averages: Copper, 30 per cent.; iron, 36 per cent.; sulphur, 26 per cent.; while the slag averages: Oxide of iron, 39 per cent.; silica, 40 per cent.; lime, 3 per cent.; alumina, 15.5 per cent.; silver, 1 ounce per ton. In the blast-furnace treatment of these ores the charge is made up of 4000 lbs. of ore, 1000 lbs. of limestone, and 525 lbs. of coke. There are three blast-furnaces measuring about 44 inches by 180 inches at the tuyeres, water-jacketed and fitted with circular fore-hearths. Blast is received at 32 ounces pressure, and each furnace is capable of smelting 300 tons daily. The blast-furnace is tapped continuously, and the gases discharge to a dust chamber; the dust carries 2.34 per cent. copper. An analysis of the matte shows 14 per cent. copper, 50 per cent. iron, and 27 per cent. sulphur. This low-grade matte is not converted on the spot, but is shipped to the Garfield smelter, where it is mixed with a higher-grade matte for converting.

II.—GOLD.

Modern Hydro-metallurgy in Australia.—Recent progress in hydro-metallurgy is discussed by J. R. Masson* and J. E. Edwards. The simplification of the stages formerly used in the treatment of heavy sulphide ore is pointed out, and details are given of the Edwards roasting furnaces, both tilting and fixed types. Two different types of furnace are made, the simplex having one row of rabblers and known as the tilting furnace, and the other known as the duplex having two rows of rabblers on the fixed-hearth principle. The customary size of the tilting type is 57 feet by 6 feet 6 inches, and of the duplex fixed-hearth type, 100 feet by 11 feet. The method of agitation in A.Z. agitators is described. This device is simple in construction, and can be applied to any circular tank. It consists essentially of a propeller placed centrally in the tank with two deflector plates, one on each side of the propeller. Details are also given of the Masson process for the treatment of antimonial gold-bearing ores. In this process the ore is ground to pass a 40-mesh screen, and is then agitated with hot solutions of caustic alkali. The antimony is found to go into solution very rapidly, usually in about two hours. The antimonial liquor is then separated from the ore and run into precipitation tanks where the antimony is precipitated very rapidly

* *Metallurgical and Chemical Engineering*, October 1910, vol. viii, pp. 584-586.

as pure metal on sheets of aluminium. After the extraction of the antimony, if the ore contains much sulphide of iron it is roasted, and then subjected to treatment with weak cyanide solution for the extraction of the gold.

Passagem (Brazil) Mine and Works.—A description is given of the deposits, methods of mining, and extraction on the Passagem Mine in Brazil, by A. J. Bensusan.*

The geological and mineralogical features are first discussed. The deposit consists of massive quartz carrying about 8 per cent. of other minerals, chiefly tourmaline and arsenical pyrites, particulars of underground workings, methods of mining, sanitary arrangements, underground lighting, ventilation, and water supply. In the treatment of the ore, it is first tipped over a grizzly for sizing and then passes to the mills where the ore is crushed to pass 30-mesh bronze or brass wire screening. The stamps weigh 750 pounds each, and give 96 blows per minute with an 8-inch drop and $3\frac{1}{2}$ -inch discharge. About 12 tons of water are used per ton of ore, and the stamp duty averages 2.9 tons per head per twenty-four hours. The resulting pulp consists of 70 per cent. sand, 23 per cent. slime, and 7 per cent. concentrate. The pulp passes over blanket strakes where 50 per cent. of the gold is recovered. The sand is treated by cyanide in vats, and the slime, after thickening, is agitated with cyanide solution and filtered by means of a vacuum filter. This plant has a capacity of 50 tons of slime per day. R. H. Kendall also describes in the same bulletin the treatment of refractory low-grade gold ores at this mine, giving details of concentration, treatment of ordinary concentrate, rich concentrate, sand and slime, the clean-up of the zinc-box precipitate, and the refining of the gold dust.

The Effect on the Solubility of Gold of Grinding Ores between Iron Surfaces.—Results of experiments are given by J. M. Tippet† on the relative solubility of gold after grinding ore between iron surfaces and between flint surfaces. The tests were made on the chlorination tailing dump of the Portland Gold Mining Company. The dump material was 14-mesh, and contained an average gold value of \$1.60 per ton. Leaching tests with cyanide were first tried on lots ranging from 2 pounds to 2 tons. This proved unsatisfactory owing to the fact that much of the gold was encased in the coarser particles, and the extraction never exceeded 50 per cent.

Crushing to 20-mesh and 30-mesh gave no better results. Grinding in an iron mortar with cyanide solution, or grinding on a bucking board so that all would pass a 200-mesh sieve, gave no improvement, but after fitting up a small tube-mill and grinding by means of pebbles in cyanide solution, the extractions rose to 70 or 80 per cent. The conclusion arrived at regarding the poor extraction obtained when the tailings are ground between iron faces was that the particles possibly became coated

* *Bulletin of the Institution of Mining and Metallurgy*, October 15, 1910, No. 73.

† *Metallurgical and Chemical Engineering*, September 1910, vol. viii, pp. 519-520.

or glazed with a film of metallic iron, which made it impossible for even strong solutions of potassium cyanide to attack them. The results of a further number of tests on the solubility of gold in chlorine water and cyanide solution after grinding (1) in a coffee-mill grinder, (2) on a bucking board, and (3) in a small tube-mill, all show that with the last method the gold is more susceptible to attack.

III.—LEAD.

Blast-Roasting of Sulphides.—H. O. Hofman * describes recent progress in the blast-roasting of sulphides, by which is meant the process of forcing air through a finely divided metallic sulphide with the object of simultaneously roasting and agglomerating. The process is divided into two great divisions according to whether the blast is forced upwards or downwards through the mass. The first-named method is practised under three modifications—the Huntington-Heberlein, the Savelsberg, and the Carmichael-Bradford processes; but with down-draught working only the Dwight-Lloyd process is in actual use. The Huntington-Heberlein process consists essentially of treatment in a roasting furnace followed by blast-roasting proper. Experience has shown that the amount of iron present should be equal to or a little in excess of the silica, otherwise trouble is experienced, and reduced tonnage, richer slags, and top-firing result. The introduction of this process at works in British Columbia has led to the lead tenor of the blast-furnace charge having been increased until it is now 40 per cent. of the weight of the ore and the flux. The blast-furnace matte, which contains up to 25 per cent. of lead, and 8 to 10 per cent. of copper, is also blast-roasted. Successful treatment is a matter of careful and systematic experimenting, as otherwise the elimination of sulphur may be too low or the proportion of residual fines too high.

The Savelsberg process is in use at works on Flat River, Missouri, for treating a non-argentiferous galena concentrate whose gangue is dolomitic limestone. The preliminary roasting is omitted, but enough limestone and silicious flux must be present to form a slag. The Carmichael-Bradford process is not, so far as the author is aware, used in the United States.

The Dwight-Lloyd process is designed to overcome the difficulties and disadvantages attending pot-roasting, which are (1) long exposure to heat, and consequent volatilisation loss; (2) intermittent operation; (3) constant attention required; (4) large amount of fines may be produced; (5) sintering is uneven; and (6) breaking the cake is expensive. The Dwight-Lloyd down-draught apparatus, on the other hand, makes but little fines; and furnishes a porous coke-like sinter which can usually be charged direct in the blast-furnace.

* *Engineering and Mining Journal*, August 13, 1910, vol. xc. p. 317.

Flue Construction and Saving of Flue Dust.—J. B. Wynne * discusses the design and construction of flues for escaping lead fumes, and the means for recovering the fumes. Illustrations are given of a new form of fume collector which is acid proof and has given excellent results in practice, besides being low in first cost, and cheap to maintain.

Lead Smelting and Refining at Trail.—A description of the plant and methods of smelting and refining lead at Trail is given by J. M. Turnbull.† The lead ore supply is mainly heavy sulphide with comparatively little dry ore, the lead furnaces carrying a charge of from 34 to 45 per cent. lead compared with the usual 10 to 15 per cent. More than 80 per cent. of the ore received contains from 20 to 75 per cent. of lead. The general procedure is to treat the heavy sulphides with lime rock, lead matte, &c., in the Huntington-Heberlein roasters and converters. The resultant lead sinter is smelted in blast-furnaces; the lead is cast into anodes, the dross being skimmed and returned to the furnace; the anodes are electrolytically refined, the products being pure lead, pure gold and silver, bluestone and sometimes antimony. The charge for the roaster is made up to contain approximately 40 to 44 per cent. lead, 10 to 13 per cent. iron, 8 to 11 per cent. silica, 7 to 10 per cent. lime, zinc being kept under 10 per cent.

When properly made up, roasted and converted, the product will be fairly hard, yellowish or greyish in colour, showing some litharge, and may be easily broken up with little fines. The plant contains 7 circular Huntington-Heberlein roasting furnaces and 24 converters, of which particulars are given. The two blast-furnaces are respectively 45 inches by 160 inches and 45 inches by 140 inches at the tuyeres, and smelt on the average 190 tons of ore per day. These furnaces are of the standard type with brick crucibles, water-jacketed to the top of the bosh, above which is a fire-brick shaft. The height of the charge is $17\frac{1}{2}$ feet above the tuyeres, and the blast used is 32 to 34 ounces. The lead bullion is tapped into a 50-ton kettle from which it is pumped into vertical anode moulds. The slag is kept at about 31 to 33 per cent. silica, 18 to 20 per cent. lime, 24 to 30 per cent. oxides of iron and manganese, 7 to 12 per cent. zinc, and 8 to 16 per cent. alumina. It carries about 1 per cent. lead and 0.4 ounce of silver per ton. The resulting bullion contains 98.5 per cent. lead, 100 ounces of silver, and 0.1 ounce of gold to the ton. The tank-room of the refinery contains 240 tanks, 3 feet by 8 feet by $3\frac{1}{2}$ feet made of coast fir lined with asphalt, arranged in six double rows in a series of cascades. The electrolyte is kept in circulation by pumps. Each tank has a capacity for 20 anodes which weigh 370 pounds each and are spaced $4\frac{1}{8}$ inches apart. Twenty-one cathodes spaced equally between and outside the anodes are contained in each tank. The electrolyte used is lead fluosilicate with free fluosilicic acid averaging 12 per cent. acid and 5 to 6 per cent. lead. A current density of 16

* *Engineering and Mining Journal*, vol. lxxxviii. pp. 602-604.

† *Mines and Minerals*, September 1910, vol. xxxi. pp. 121-125.

amperes per square foot of cathode area is used, but it is proposed to reduce this to 12 amperes, which is found to give better results. A tank is worked out in about eight days, 15 per cent. of scrap going back to the melting-pot after washing. The slime is first agitated with hot water, then filtered and dried and melted in a water-jacketed reverberatory furnace lined with magnesite brick. The impurities are oxidised off and doré bullion obtained which is parted in sulphuric acid. The McNab antimony process, which is sometimes used, consists of dissolving the antimony and arsenic from the slime by boiling with sodium polysulphide and electrolysing the solution with lead-sheet anodes and steel-sheet cathodes, the cathode deposit being a dense hard antimony with 2 per cent. arsenic which is removed by melting with alkaline fluxes.

IV.—RARE METALS.

Treatment of Cobalt-Nickel Ores.—Experiments on the treatment of Canadian cobalt-nickel ores are described by C. C. Cito* in a paper read before the American Electrochemical Society, May 1910. The ores contain, besides cobalt and nickel, large quantities of silver and arsenic, and are found in Northern Ontario, to the east of Lake Superior, with the centre in Cobalt City. The author briefly describes the results of experiments on the treatment of the ore by all the methods, either wet or dry, already in use for the treatment of similar silver ores, but all these gave more or less unsatisfactory results. After further experiments a combined process of smelting and electrolytic treatment was devised which proved successful. The following is a résumé of the results obtained:—

I. *Mechanical Concentration.*—On grinding and sieving, the silver was found to be practically equally divided between the metallics and the fines. The fines are therefore so much poorer that their further treatment is less profitable.

II. *Wet Processes.*—(a) With raw ore: leaching with potassium cyanide, hydrochloric acid and sulphuric acid. (b) With roasted ore: leaching with sodium chloride, sodium thiosulphate, sodium-copper thiosulphate, potassium cyanide, hydrochloric acid, sulphuric acid, magnesium chloride and ammonia. In all these experiments the results were unsatisfactory, for the silver, on the one hand, did not dissolve completely, even with large quantities of solvent; nickel, cobalt, and arsenic, on the other hand, when they should have dissolved, remained to a large extent in the residue, while considerable quantities of silver passed into solution. The working up of the solutions and residues would therefore lead to a great many intermediate products and become complicated.

III. *Dry Processes.*—(1) Roasting Experiments. These were tried as a means of driving off the arsenic and also as a means of rendering the

* *Metallurgical and Chemical Engineering*, June 1910, vol. viii. pp. 341-344.

silver soluble by the aid of certain reagents. The results, however, showed too large a loss of silver and also too small an elimination of arsenic.

(2) Smelting Experiments. (a) Smelting with Lead Fluxes. In these experiments, the ore, after roasting with charcoal and galena, was smelted in a blast-furnace with usual fluxes, producing metallic lead, a speiss, a matte and a slag. The products were not satisfactory. Nickel, cobalt, and silver were found in all four products in such amounts that the further treatment of these would be very complicated and uneconomical.

(b) Smelting with Copper Fluxes. The object of this smelting is to obtain an alloy containing all the cobalt, nickel, and silver, which could be worked up as an anode in an electrolytic bath and a clean slag. In order to produce this alloy it was found necessary that the copper present should be at least two-thirds in amount of that of the nickel and cobalt and at least the same as that of the arsenic. As a result of the electrolytic treatment of this alloy, in a sulphuric acid solution of copper sulphate, pure copper is obtained at the cathode, silver is obtained as slime, nickel and cobalt remain in solution in the electrolyte, and at the proper temperature the larger quantity of arsenic also remains in solution, the balance being in the slime. The slimes are treated by a roasting or dissolving process, and the silver is then refined by cupellation. The electrolyte containing copper, arsenic, nickel, and cobalt is periodically treated for the separation of these metals by well-known means.

Tungsten.—W. C. Prosser* notes the occurrence of tungsten in San Juan County, Colorado. It is met with as hübnerite widely distributed over the Silverton quadrangle, and on concentration a 40 to 50 per cent. tungsten product has been obtained. The main deposits are confined to a district about nine miles long.

V.—TIN.

Smelting Bolivian Tin Ores in Germany.—The Bolivian tin deposits of Oruro, Potosi, &c., occur in quartz-trachyte, and contain much sulphur. They are imported by Hamburg, and, as stated by H. Schüpphaus,† are first subjected to oxidising roasting. Three classes of material are smelted—(1) Ores with up to 67 per cent. of tin and traces of copper and lead. (2) Ores with medium or high tin and containing copper and lead. (3) Ores with only 40 to 50 per cent. of tin, and with much lead, copper, and antimony. The quantity of lime and anthracite to be added is calculated on the basis of the analysis. Smelting takes place in Cornish furnaces. The tin obtained is liquated and then poled with wood in iron vessels holding 6 or 7 tons. Three qualities of tin are made, with 99·15–99·8 per cent., 98 per cent., and

* *Engineering and Mining Journal*, August 13, 1910, vol. xc. p. 320.

† *Metallurgie*, 1910, vol. vii. p. 539.

93-96 per cent. of tin respectively, as well as alloys of lead and tin for use as solders. The reverberatory slag contains 18-25 per cent. of tin, and is smelted with iron and anthracite.

VI.—SILVER.

Continuous Pachuca Tank Agitation.—The agitation equipment of the new cyanide plant of the Esperanza Mining Company, El Oro, Mexico, is described by M. H. Kuryla* in a paper presented to the Instituto Mexicano de Minas y Metalurgia, April 1910. The author first describes the original intermittent system, and then describes the present continuous system in which six tanks are arranged in series, the pulp being fed into the top of No. 1 tank at the rate of 300 tons of dry slime and 540 tons of solution per twenty-four hours, and flows through the six tanks to the discharge bore near the top of No. 6 tank.

The friction drop from tank to tank is about 6 inches, making a total drop in the level of the pulp 30 inches. This difference in level is reduced to 12 inches by utilising the central tube as an air-lift and arranging for the overflow of the air-lift to drop into the discharge launder. The gain of extraction in the continuous system as compared with the intermittent system is 1.3 per cent. gold and 1.5 per cent. silver, and the saving in cyanide 25 grammes per ton of ore treated.

Cyaniding Silver Ores in Mexico.—In a paper read before the Mining and Metallurgical Institute of Mexico, August 1909, E. Girault† describes the plant for treatment of ores from the San Rafael Mines, together with methods, results, and costs.

The ore contains 70-75 per cent. silica and 10-20 per cent. calcite as gangue. The silver exists mostly as silver sulphide, associated with varying proportions of iron pyrites, galena, and zinc-blende.

The gold occurs in nearly constant proportions of 3 or 5 grammes per ton. All ores carrying more than 300 grammes of silver to the ton are cyanided. After sorting and crushing the ore is treated by the following method:—(1) Pulverised with stamps in a solution containing 2.5 kilogrammes of potassium cyanide per ton of water. (2) Concentrated on Wilfley tables. (3) Tailings are classified. (4) Sands from classifiers are ground fine in Krupp tube-mills. (5) Material from Krupp mills is settled in pulp thickeners. (6) Thickened pulp is agitated in Pachuca tanks. (7) Slime is separated by Moore vacuum filters. (8) Gold and silver in solution is precipitated on zinc filaments.

From 6 to 12 kilogrammes of lime is added in the bins per ton of ore, the alkalinity of the solution being kept at 1 kilogramme of calcium oxide per ton of ore. The mill solution averages 0.25 per cent. potassium cyanide, and there is a cyanide loss of about 600 grammes per ton of ore. The extraction of silver and gold in the crushing operations is

* *Metallurgical and Chemical Engineering*, July 1910, vol. viii. pp. 416-417.

† *Mines and Minerals*, May 1910, vol. xxx. pp. 618-620.

high, averaging one month, 38·3 per cent. of the silver and 70 per cent. of the gold. For the precipitation of the precious metals, zinc shavings 0·006 inch thick are used. Two tons of solution per ton of ore are precipitated. The heads in the boxes assay from 200 to 300 grammes of silver; the tailings 2 grammes.

Silver Lead in the Shan States.—T. D. Latonche* and J. C. Brown describe the silver lead deposits of the Shan States, with special reference to the Baldwin Mines, which are believed to have been worked for over a thousand years, although the earliest authentic records do not go further back than 1412 A.D. The Chinese worked these mines for the sake of the silver and threw the slags away, but as they contained as much as 50 per cent. of lead, they are now being profitably worked for recovery, while below the surface of the old workings much of the original ore still remains to be extracted. The mines are situated at the northern border of the State of Tawng Peng. The country for several miles south of the mine is impenetrable jungle. The geology of the area is somewhat confused and difficult to follow. The chief structural feature is the great overthrust which can be traced continuously for about thirty miles. The ore occurs as nodular masses of finely crystallised galena associated with zinc-blende and specks of copper pyrites. The surrounding rock is rotten owing to the formation of soluble sulphates and carbonates. Beds of massive barytes also occur. A description is given of the old Chinese workings, and the future prospects are discussed. The slags contain 47·8 to 49·3 per cent. of lead, 16·7 to 18·20 per cent. of zinc, 2·5 ounces of silver, and variable amounts of gold. The heaps are quite accessible, and are estimated to contain 110,000 to 125,000 tons.

VII.—MISCELLANEOUS.

Arsenic Manufacture at Midvale.—Details are given by L. A. Palmer† of the plant at Midvale for the roasting of arsenic ores and condensing and refining the fume. The first treatment is carried out in a special design of reverberatory furnace invented by D. W. Brunton, full details of which are given. The unrefined arsenic carries 97 to 99 per cent. arsenious acid deposits in flues, the last portion being retained by means of a bag-house. Each furnace has a capacity of 16½ tons of material per day. The refining furnace is of the simple reverberatory type, the hearth being 10 feet by 20 feet. The temperature is about 700° in the furnace and 100° at the extreme end of the settling chamber. This furnace has a capacity of 15 tons per day, and the product analyses 99·87 per cent. of white arsenic. The impurities of both the unrefined and refined arsenic are chiefly antimony and lead arsenate. The refined arsenic, which is in crystalline form, is ground to make a commercial product.

* *Engineering and Mining Journal*, vol. lxxxviii. pp. 550-555.

† *Mines and Minerals*, June 1910, vol. xxx. pp. 641-644.

ELECTRO-METALLURGY.

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I.—ELECTRIC SMELTING.

Electric Smelting of Nickel Ore.—A description is given of an electric smelting method, devised by C. T. Hennig,* for the treatment of the nickel ore deposits of Webster which have previously been treated by various leaching methods. The ore at Webster consists essentially of hydrated nickel-magnesian silicates, chiefly apple-green garnierite and brown dunite. The garnierite is richer in nickel, containing on the average 5 per cent., whilst the dunite contains 1·5 to 2·0 per cent. nickel. It has been found that these ores can be converted into marketable products by a simple direct reduction with coke in an electric furnace. The product of the smelting is a silicide of nickel and iron containing small quantities of chromium, aluminium, and magnesium, and less than 1 per cent. of carbon. The molten slag and metal are tapped into large moulds or slag pots, and a clean separation is effected. The nickel silicide is directly applicable for making nickel steel. The electric furnace is made of a sheet-steel shell $\frac{3}{8}$ inch thick, 6 feet in diameter and 5 feet high, and is bolted on to a $\frac{3}{4}$ -inch plate which is connected to one pole of the electric circuit. The bottom of the furnace thus serves as one electrode. It is formed of a number of iron rods cast into the base-plate to act as conductors. Around these iron rods carbon is rammed to form the hearth. The furnace is covered with a cap through which the other electrode is suspended.

Electrolytic Preparation of Magnesium.—Various experiments on the preparation of magnesium by the electrolysis of fused salts are described by S. A. Tucker† and F. L. Jouard, in a paper read before the Pittsburgh Meeting of the American Electrochemical Society. The

* *Metallurgical and Chemical Engineering*, May 1910, vol. viii, pp. 277-279.

† *Ibid.*, June 1910, vol. viii, pp. 333-335.

authors sum up their results as follows :—Magnesium can be obtained by electrolysis of its molten chloride in presence of potassium chloride, preferably in a carbon or graphite crucible, but the bath is troublesome and expensive to prepare. The current efficiency may run as high as 60 per cent. The presence of magnesium oxide is to be avoided. A small proportion of calcium fluoride tends to consolidate the metal. In this process, changes of current density and of temperature have comparatively little effect unless these changes are very great.

Electrolysis of magnesium fluoride and other fluorides, as additions for dissolving oxide of magnesium, gave practically no metal, and there seems to be direct solution of magnesium in such molten compounds.

Alloys of magnesium with aluminium or copper are easily made by electrolysis with the use of a chloride bath, but they have no special advantage from the standpoint of current efficiency as compared to the process for making pure magnesium. The electrolytic decomposition of the alloy containing aluminium for the recovery of the magnesium was unsuccessful.

II.—ELECTRIC FURNACES.

An Experimental Furnace.—An experimental electric furnace for heating in a vacuum is described by O. Ruff.* When used as a resistance furnace, the heater is a carbon cylinder, the resistance of which may be increased for work at very high temperatures by cutting numerous slots through the carbon walls. The terminals are of iron, cooled by water and attached by screws to the copper-plated carbon blocks which hold the heating tube. The furnace is enclosed in a double-walled brass jacket cooled by water. Temperatures are determined by means of an optical pyrometer, sighted on the interior of the carbon tube through quartz windows. The gas is exhausted by a rotatory oil-pump, which reduces the pressure in three minutes to 3 millimetres.

The motor generator used gives 10 to 80 volts and up to 1000 amperes, the voltage being capable of being regulated to a fraction of a volt. A temperature of 2700° is attainable with 650 amperes, and the furnace may be run for several hours at 2000° – 2200° without injury. It is necessary to use carbon crucibles at such high temperatures. Tungsten is of little use for crucibles, being even more volatile than carbon. The same furnace may be conveniently worked as an arc furnace.

A few measurements obtained with the carbon resistance and Wanner pyrometer are: Melting-points of molybdenum, 2110° ; iridium, 2210° – 2225° ; kaolin, 1912° – 1915° ; and tungsten (92.2 per cent.), 2575° . Titanium, containing 5 per cent. of carbon, is only slightly sintered at 2700° . Alumina melts to a thin liquid at 2065° , and is volatile even at 1900° . Lime volatilises at 2035° , forming felted needles, which prevent the determination of the melting-point. Magnesia is very volatile at

* *Berichte der deutschen chemischen Gesellschaft*, 1910, vol. xliii, p. 1564.

2100°. It has been found possible to measure the electrical conductivity of these oxides, and the results show that a sudden fall in the resistance occurs on melting.

Determination of the Constants of Electrode Materials and Empirical Laws of Furnace Electrodes.—C. Hering * describes in detail the method of determining the constants of materials for furnace electrodes, which consists in imbedding a rod of the material to be tested in a heat-insulating material, allowing the ends to project sufficiently for terminals, passing a current through as a source of heat, and taking readings of the temperatures at the ends and middle, the voltage at the two ends and the current.

From the data thus obtained all the necessary physical constants are calculated. For example, the resistance is the quotient of the volts and the amperes; from this and the size of the rod the mean resistance is calculated. The heat flow in watts is the product of the volts and amperes, and from this and the dimensions the heat conductivity is calculated. A table is given of the observed data for electrodes of carbon, graphite, iron, and copper. In the second paper the same author analyses the results thus obtained with a view of finding out whether any of the physical properties involved follow some approximate general laws. It is shown that empirical laws may be found for the values of the two simple and determining factors E and S^1 , which together are all required for calculating an electrode.

E measured in volts represents the specific loss in watts for any particular range of temperature, and S^1 is the specific section, that is the cross section required per ampere per inch of length in order that there shall be no flow of heat either way through the furnace end.

Electric Furnaces in Non-Ferrous Metallurgy.—The suitability of electric furnaces to non-ferrous metallurgy is discussed by J. W. Richards,† who divides the furnace operations involved into six principal classes, as follows:—

1. The melting of metals for refining and casting. The advantages of electric furnaces, using no fuel, and producing no ash, are mentioned especially for those metals injured by furnace gases.

2. The melting together of metals to produce alloys. In this case the electric furnace provides the means for producing at one heat several tons of alloy, all uniform in composition, and without any necessary losses by oxidation. A great extension of the use of electric furnaces is expected in the manufacture of such alloys as brass, bronzes, German silver, standard silver, alloyed gold, &c.

3. The roasting of sulphide and arsenide ores. In this case the substitution of electricity for fuel will have advantages, and will be advisable if the electrical energy can be obtained sufficiently cheaply.

4. The concentrating roasting of raw ore or partly roasted ore to

* *American Electrochemical Society Transactions*, 1910, vol. xvii. pp. 151-222.

† *Metallurgical and Chemical Engineering*, May 1910, vol. viii. pp. 233-234.

matte. In this operation electric heating would not be applied to ores sufficiently pyritic for "pyritic smelting," but for other ores some of the electric shaft furnaces already operated for iron ores would be suitable, if provided with tuyeres above the electrodes to perform whatever oxidation of the sulphides of the charge was desired.

5. The reducing smelting of raw or roasted ores to metal. In this operation, whether carried out in reverberatory furnaces or shaft furnaces, electrical energy could be used provided the cost compared favourably to the cost of fuel. The advantages of electrical shaft furnaces over solid fuel furnaces are absence of large quantities of products of combustion and consequent decrease in volatilisation and fume loss, the absence of the relatively high temperature of combustion in the tuyere region, and the regulation of the maximum temperature in the furnace to simply that required for the running out of the products. In this case sufficient carbon would be added for the reduction of the charge, but none for fuel.

6. The reducing smelting of raw or roasted ores to metal vapour which is to be condensed. In this operation as applied to zinc, for example, electrical energy offers great promise, because electrical energy can be converted into heat inside the retorts or chambers without having any but the usual gases in the retort. Many metallurgists are now working on this problem.

Elementary Principles of the Designing and Proportioning of Electrical Furnaces.—A summary of the principles involved in electrical furnace design is given by C. Hering.* The author points out that no great difference exists between arc and resistance furnaces except in matters of detail. The arc is really a gaseous resistor. In this feature, therefore, the arc furnace is really a resistance furnace with a very small resistor.

The first step in the design of a furnace is to decide upon the output and the rate per hour, for neither the size of the furnace nor the power input will depend upon the former alone.

The next step is to calculate the theoretical amount of energy required for the chemical and physical changes of the specified amount of the product, as that will represent the least possible energy. In the next place, the amount of current and voltage are decided upon. This will depend greatly on the construction of the furnace and will be governed by it.

Then follows the determination of the size of the furnace, which should be made as small as practicable to hold the material.

After this the shape and thickness of the walls must be decided. A sphere is theoretically the best as far as heat loss through the walls is concerned. A cubic shape is better than a long rectangle or cylinder. These various points are dealt with in detail in the article, and the best means of correcting certain mistakes in the construction are given.

* *Metallurgical and Chemical Engineering*, August 1910, vol. viii, pp. 471-473.

Induction Furnace Progress.—A review of the recent progress made in the simple induction furnace and in the combination furnace is given in a paper by T. Rowlands,* read before the Pittsburgh Meeting of the American Electrochemical Society.

The simple induction furnaces are of the Kjellin-Colby design, and intended for melting purposes only. Details are given of experimental runs for the melting of charges of metallic nickel, the special interest of which was the rapidity of melting. Brass melting in the simple induction furnace has been carried out in England. To overcome troubles with the pinch effect, a special crucible was employed, together with a specially constructed coil on the furnace, whereby the electrical conditions could be so changed that at any desired moment most of the current could be carried either by the metal in the bath or by the crucible itself. By this arrangement the crucible is first heated, and, when sufficiently hot, the brass scrap is charged. This soon melts, completing the circuit. The switch is then thrown over and the metal itself carries most of the current.

New Resistance Furnace.—F. A. J. FitzGerald † describes a new furnace in which the crucible is heated by radiation from resistance instead of from arc. In some forms of this furnace, such as have been used for the experimental production of zinc, the reaction or heating chamber is sealed. The efficiencies of these furnaces are given as 74 to 76 per cent.

In some forms of electric furnaces it is possible to practically eliminate the loss of electrically generated heat by surrounding the body with an envelope of gas, and in the type of furnace above mentioned this is accomplished by building the furnace with double walls, bottom and cover, and between the inner and outer parts burning fuel which keeps the temperature there the same, or nearly the same, as that in the working chamber. Experiments on large furnaces have shown that this modification introduces very great economies.

Output and Efficiency of Electric Furnaces.—The possibility of improving the output and efficiency of existing electric furnaces is dealt with by C. Hering,‡ who describes simple methods and rules by means of which it may readily be determined whether such improvements can be made by mere changes in the electrodes without a complete change of design of the furnace.

Small High-Temperature Furnace.—Details are given of the construction of a small convenient and inexpensive furnace for high-temperature work by D. F. Calhane.§ The furnace has been used by the author for two years, and is made up of inexpensive materials con-

* *Metallurgical and Chemical Engineering*, June 1910, vol. viii. pp. 337-340.

† *Ibid.*, p. 317.

‡ *Ibid.*, May 1910, vol. viii. pp. 276-277.

§ *Ibid.*, October 1910, vol. viii. pp. 581-582.

sisting essentially of a graphite crucible surrounded by a carbon resister. It is most useful for making up alloys with high melting-points where carbon contamination is undesirable.

III.—ELECTRO-REFINING.

Cuprous Chloride Solutions and Copper Refining.—The advantage and possibility of using cuprous chloride solution in copper refining is discussed by M. de Kay Thompson * and E. R. Hamilton in a paper read before the American Electrochemical Society, May 1910. It is pointed out that if the resistance of cuprous chloride solution were the same as the copper-sulphate solution universally employed in copper refining, and if the former worked otherwise satisfactorily, it is evident that the power used in refining the same amount of copper could be halved. The conductivities of various solutions containing cuprous chloride, sodium chloride, and hydrochloric acid are given, and compared with ordinary acid solutions of copper sulphate such as are used in copper refining. It is found that the conductivity of cuprous chloride solution can be made as high as that of solutions ordinarily used in copper refining by the addition of hydrochloric acid, and further experiments showed that at room temperatures a current efficiency of 90 per cent. of the theoretical can be obtained when the solutions are acidified.

Electrolytic Lead Refining and Plating.—Experiments on the lead perchlorate refining and plating bath are described by F. C. Mathers † in a paper read before the American Electrochemical Society, May 1910. The properties of lead perchlorate, which are of special value in a plating or refining solution, are—great solubility; smoothness and denseness of cathode deposits and freedom from “trees”; approximately theoretical corrosion of the anode and deposition upon the cathode; absolute stability under all conditions to which it is subjected in a plating or refining bath; no polarisation from the formation of lead peroxide on the anode; and very high electrical conductivity. Sodium perchlorate was used as a starting material for the preparation of the perchloric acid and treated with hydrochloric acid, filtered and heated to 135° C. The lead perchlorate was made by neutralising the aqueous perchloric acid thus prepared with litharge. The electro-plating or refining bath should contain about 5 per cent. of lead, 2 to 5 per cent. of perchloric acid, and 0.05 per cent. of peptone as a suitable “addition substance.” Without some addition substance the lead perchlorate bath does not give good deposits except at very low current densities. A current density of from 18 to 27 amperes per square foot may be used. The peptone is gradually used up, and after about four days a quantity equal to the original amount should be added. The free acid, which is very slowly neutralised by chemical solution of the lead, must be restored by the treatment of a

* *Metallurgical and Chemical Engineering*, June 1910, vol. viii. pp. 347-348.

† *Ibid.*, p. 350.

suitable portion of the solution with the right amount of sulphuric acid. This precipitates lead sulphate, and leaves perchloric acid in solution. The filtrate from this is returned to the bath. The bath gives excellent purification, the cathode being about 99.98 per cent. pure. The deposit is smooth, coherent, and has a density of 11.36. The bath shows no deterioration with use, and gives as good deposits after two months as at the beginning, if the concentration, acidity, and the required amount of peptone are maintained. The author sees no reason why the perchlorate bath cannot be applied on a commercial scale, especially for lead plating, since the deposits are of exceptional smoothness and entirely free from "trees" or loose crystals on the edges or points.

Electrolytic Refining of Bullion in the United States Mints.—The electrolytic processes employed in the Government Mints in the United States are specially designed to deal with a bullion containing a mixture of gold, silver, and base metals in all proportions. The system in use is a double one, the first step being to bring the silver up to purity, and the second the gold. Both processes are described. They admit of subsequent recovery of the platinum and palladium present, a source of income formerly lost.*

Electrolytic Refining of Copper.—A full detailed account of the electrolytic refining of auriferous and argentiferous copper at Lithgow, New South Wales, is given by G. H. Blakemore,† taken from the *Proceedings of the Australasian Institute of Mining Engineers*, February 1910. Each vat carries nine large anodes and nine cathode bars with two cathodes on each. The vats are made of Oregon pine, dipped for about ten minutes in boiling paraffin wax. They are lined with sheet lead of 6 pounds to the square foot, the linings being brought over the top edge of the tanks. The fall of level between tanks is 3 inches, the electrolyte flowing from one tank to the other in cascade fashion. The first secret and most important point of electrolytic refining is efficient insulation. Cleanliness is the next secret; all connections must be kept bright and clean. From the eighth tank the electrolyte flows into a sump launder, and thence to the collecting tank. It is then elevated into sand filters to separate slime carrying gold and silver. The temperature of the electrolyte at this plant is kept at 120° to 130° F.

This temperature is maintained by passing waste steam through lead coils in the supply tanks. The higher temperature reduces the resistance of the electrolyte and causes a more even deposition of the copper, especially where the free acid is above 8 per cent.

By using hot electrolyte and high percentage of acid, the sluices are found to contain much less copper. Each vat is separately agitated by a jet of compressed air at a pressure of 5 pounds per square inch. At Lithgow the composition of the electrolyte is: Free sulphuric acid, 12

* *Engineering and Mining Journal*, July 30, vol. xc. p. 214.

† *Mines and Minerals*, June 1910, vol. xxx. pp. 648-652; July 1910, vol. xxx. pp. 746-750.

per cent.; bluestone ($\text{CuSO}_4 + 5\text{H}_2\text{O}$), 14 per cent.; specific gravity, 1.18. The blister copper is first refined in reverberatory furnaces to bring it up to 99.4 or 99.6 per cent. copper, and is then cast into anodes. About 20 amperes per square foot of cathode surface is found to be a good working current.

In about three weeks the anodes are eaten so thin that the remnant has to be removed. As they begin to be attacked the insoluble impurities—gold, silver, selenium, &c.—show on the surface of the anode as a dark greenish slime which slides off at irregular intervals to the bottom of the tank. Iron goes into solution. The mud is taken from the tanks at regular intervals and sieved to remove the coarse particles of copper. The sieved mud is washed fairly free from copper sulphate, slowly dried in trays, then heated to a dull red. The product is boiled in concentrated sulphuric acid in a cast-iron pan to dissolve most of the copper. The residue is then washed, dried, and fused in a small cupel furnace with carbonate of soda to doré silver which usually assays 12 to 16 per cent. gold and 82 to 86 per cent. silver. This doré silver is parted in a small plant on the Mœbius principle, consisting of small tanks using about 150 to 200 amperes at 2 to 3 volts. The electrolyte for this plant contains 15 ounces of silver to a gallon as nitrate. The anodes are hung in calico bags in order to collect the gold as it separates. The silver collects on the cathode in a crystalline form, and is removed by wooden arms.

Many other particulars are given on clearing and assaying the electrolyte, &c.

Electrolytic Winning and Refining of Metals.—A process for treating mattes and speisses in the fused state by electrolysis is suggested by E. M. Chance* in a paper read before the American Electrochemical Society, May 1910. The author considers that insuperable obstacles would lie in the way of commercially applying Aiken's process for the electrolysis of mattes containing nickel, copper, and iron directly in the fused state, and proposes a process in which a fused electrolyte is superimposed upon the fused matte. At the temperature required for the operation, the most troublesome elements—arsenic, antimony, and sulphur—would volatilise.

Experiments were made on a copper-iron matte, using as electrolyte sodium metasilicate. It was found that by controlling the difference in potential across the poles a very pure copper could be deposited on the cathode, iron remaining in the electrolyte as silicate. With a nickel-copper-iron matte the copper could be deposited selectively, and when all the copper had been removed from the electrolyte, the nickel could be deposited free from iron by increasing the electromotive force. The voltage must be kept below that at which the iron silicate is decomposed. In the case of speisses, the arsenic and antimony appeared to volatilise quantitatively. Attempts were made to use halogen salts in the place of silicates, but at the temperatures used, chlorides of the alkalis and

* *Metallurgical and Chemical Engineering*, June 1910, vol. viii. p. 354.

alkaline earths were both volatile and unstable, while calcium fluoride was not sufficiently fluid. Sodium chloride was very useful in the electrolysis of alloys with low fusion points such as silver-lead.

The author mentions that by this process a very good separation of silver from lead in a silver-lead bullion was made. This alloy was attacked with a sodium-lead silicate electrolyte, the lead being carried over to the cathode while the silver remained unattacked at the anode.

Modern Electro-Plating Plant.—The electro-plating plant * of the National Cash Register Company, Dayton, Ohio, is described in detail.

In the main room are 105 plating tanks, each equipped with individual rheostat, voltmeter, and ammeter. Ninety-three tanks are devoted to "wire-work"—that is, the plating of comparatively large pieces, which are suspended by copper wires; the other twelve tanks are provided with wicker-work baskets, each basket having a capacity of two or three pailfuls of small inside parts, bolts, nuts, &c.

Several cleaning tanks are provided. The castings to be cleaned are put in as cathodes, and the violent bubbling of hydrogen loosens the oil, polishing powder, scale, and other discolorations.

Iron and steel only are treated in this way, as an automatic method for satisfactorily cleaning bronze does not yet seem to have been discovered.

Bronze castings are soaked in soapy water, scrubbed with a hand brush, and dipped in weak lye water. Pickling tanks for hydrofluoric, sulphuric, and muriatic acids are provided, and the fumes are carried off by fans.

The solutions used for various finishes include the following :—

Nickel.—Double sulphate of nickel and ammonia.

Copper.—(a) Copper cyanide; (b) copper sulphate.

Silver.—Cyanide and chloride of silver.

Zinc.—Sulphate of zinc acidified with a little sulphuric acid.

For cleaning, crude potash and carbonates of potash and soda are used. The total amount of standard solutions in use is 47,200 gallons.

Nickel plate can be applied direct to any metal without a preliminary coating of copper, as was formerly thought necessary. A very low voltage is being used, $1\frac{3}{4}$ volts on wired work. This is to avoid gritting, and to make a softer coat which will take the polish better. Zinc, on the other hand, can be put on very rapidly, 6 volts being used on wired work. Copper requires first a cyanide solution to act as a binder. A transfer is then made to the faster acid sulphate solution for the heavy run. Silver plating is put on in about five minutes after a heavy base coat of nickel has been deposited.

* *Metallurgical and Chemical Engineering*, May 1910, vol. viii. pp. 274-275.

IV.—ELECTRO-DEPOSITION.

Electro-Deposition of Platinum.—A report of their continued researches on the electro-deposition of platinum is given by W. J. McCaughey * and H. E. Patten. The authors employed aqueous solutions of potassium chlorplatinat and of ammonium chlorplatinat with or without citric acid. The conditions of producing the different forms of platinum deposit were studied, and, in addition, anode and cathode discharge potentials were taken to assist in the interpretation of the differences observed in the deposits of platinum and the result of citric acid additions. The results are given in detail in numerous tables.

Electrolytic Reduction of Tin.—An electrolytic method for the reduction of cassiterite is suggested by W. O. Snelling † in a paper read before the American Electrochemical Society, May 1910. The method is based on an observation made in a laboratory experiment in which cassiterite, in contact with zinc in hydrochloric acid, was directly reduced by cathodic action. This system represented a short-circuited galvanic cell with zinc as anode and cassiterite as cathode. When zinc and cassiterite are in contact a current passes through the hydrochloric acid solution from the zinc to the cassiterite, the zinc goes into solution and the cassiterite is reduced to tin. The author tried experiments on a small scale by using a double compartment cell in which the cassiterite was first reduced to the metallic state, and then by the throw of a double-pole switch the current was reversed, a plating action resulting, the deposit being practically 99 per cent. pure.

V.—MISCELLANEOUS.

Chemical Reactions at Electrodes.—In an address delivered before the New York Section of the American Electrochemical Society, R. Stevenson ‡ reviews the broad field of electrochemical reactions in liquid solutions. The reactions which occur at electrodes are classified as follows, and the various factors concerned in the equilibrium of these reactions are considered :—

1. The discharged ion reacts with itself.
2. The discharged ion dissolves in the electrode.
3. The discharged ion reacts with the electrode.
4. The discharged ion dissolves in the solution.
5. The discharged ion reacts with the solvent.

* Paper read before the American Electrochemical Society, May 1910; Abstract, *Metallurgical and Chemical Engineering*, June 1910, vol. viii. pp. 349-350.

† *Ibid.*, p. 347.

‡ *Ibid.*, May 1910, vol. viii. pp. 240-243.

6. The discharged ion reacts with the solute.
7. The discharged ion reacts with suspended particles.
8. The discharged ion reacts with dissimilar ions of similar charge.
9. The discharged ions of dissimilar charge react with each other.
10. The reaction products which are at first formed break down and form secondary products.
11. The products at the electrodes diffuse and react away from the electrodes.
12. Electrolysis with alternating current.
13. Electric endosmose.
14. Electrostenolysis.
15. Reversed electrolysis.

Of these reactions, the nature, extent, and velocity may be affected by the following variable factors of equilibrium—temperature, pressure, concentration and nature of the electrolyte, current density, light, diffusion, electromotive force, nature and concentration of electrodes, and catalytic action. In any one reaction many or all of these factors might change, so that the effect would be the resultant of many different forces.

The effect of the variation of each factor while the others remain constant is considered, and many examples are given.

In conclusion, the author states that reactions at electrodes differ from ordinary reactions in the following ways:—

1. Energy is used instead of matter. The amount of substance used in electrochemical reductions and oxidations is small, and its active principle is regenerated by electrical energy and used repeatedly.
2. Localisation of effect.
3. Two dissimilar reactions occur simultaneously.
4. The regulation of the reaction velocity is easy.

Bancroft has shown the identity of chemical reactions and electrode reactions, and has shown that the same variables affect the equilibrium in both cases.

THE PROPERTIES OF METALS AND ALLOYS.

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I.—COMMON METALS.

Allotropic Change in Zinc.—Zinc is well known to undergo a marked change in electrical conductivity at about 340° , whilst the increase of malleability at a much lower temperature points to a second change. C. Benedicks* now finds that the conductivity of pure zinc undergoes changes at 170° and 340° . On the other hand, commercial rolled zinc (one sample from Schoppinitz, Upper Silesia, the other of unknown origin) showed a most remarkable change, the specific resistance having a very pronounced maximum at 300° – 310° , and diminishing to a minimum at about 380° , and again increasing. Such a behaviour has hitherto only been observed in copper-nickel, copper-manganese, and ternary manganese alloys. The conductivity of liquid zinc is greater than that of the solid metal.

Influence of Impurities on the Properties of Copper.—A series of notes on the effects of traces of impurities on the physical and mechanical properties of copper are published by F. Johnson.† These notes are based on the observations of other workers, and are amplified by the author's own work.

Arsenic hardens, toughens, increases tensile strength and ductility when present up to at least 1·5 per cent. It invariably improves the forging properties of impure copper. It is largely specified for in material required to withstand high temperatures. Arsenic lowers the electrical conductivity of copper in a most pronounced manner. Arsenic improves the hot-working properties of copper vitiated by traces of bismuth.

* *Metallurgie*, 1910, vol. vii. p. 531.

† *Metallurgical and Chemical Engineering*, October 1910, vol. viii. pp. 570–575.

Lead is found in all ordinary commercial copper, but is not desirable in any proportion over 0.1 per cent. The lead reduces the strength, ductility, and toughness, and renders the copper more susceptible to "burning."

Nickel in traces is beneficial to copper, imparting strength, toughness, and increased resistance to deformation at high temperatures. Nickel must be kept low when arsenic is present.

Bismuth has by far the most deleterious action of all the impurities found in copper. One hundredth per cent. renders copper less malleable at a red heat, but by regulating the proportions of arsenic and oxygen the author has obtained very respectable tensile results even with 0.1 per cent. bismuth.

Cobalt.—Little is known about the influence of this metal on copper, but the author's experiments tend to show that it toughens and strengthens copper when present up to at least 1 per cent. without impairing its hot-working properties.

Antimony hardens and strengthens copper, and is not detrimental when present up to 0.5 per cent. if other impurities are absent and a small percentage of oxygen is present. When used for alloying, copper should be free from antimony.

Tellurium.—Very little is known of the effect of tellurium on commercial copper. Huntington thinks that minute traces of tellurium are not so harmful by themselves as when present with similar traces of bismuth.

Iron occurs in refined copper in the merest traces, which are quite harmless. It acts as a deoxidiser when added to copper, and 1 per cent. renders the metal feebly magnetic.

Tin hardens copper more than any other element. Low percentages of tin improve the tensile strength, ductility, and resistance to corrosion, and maintain these improvements at high temperatures.

Silver is rarely present in sufficiently high percentage to impair either the hot or cold working properties of copper. It is more injurious on the hot-working properties when arsenic is absent.

Sulphur rarely occurs in more than harmless traces in commercial copper, yet it may occur to the extent of 0.03 per cent. in electrolytic copper having a conductivity of 101.2 per cent.

Oxygen.—All furnace-refined copper contains some oxygen. The amount will depend on the quantity and nature of the impurities present and upon the skill of the refiner. Oxygen is essential in all commercial impure wrought copper which has to withstand repetitions of small stresses, exposure to atmosphere, influence of corrosive agents or varying thermal conditions.

Segregation of Impurities.—There seems to be no analogy of segregation of impurities in copper as occurs in iron and steel. The solvent action of molten copper is remarkable, and absence of segregation would seem to confirm a perpetuation of this property through a falling temperature. The precious metals do segregate in copper to a marked degree.

II.—RARE METALS.

Ductile Tungsten and Molybdenum.—The properties of ductile tungsten and molybdenum are given in a paper by C. G. Fink,* read before the Pittsburgh Meeting of the American Electrochemical Society, May 1910. Ductile tungsten is a bright, tough, steel-coloured metal which can be drawn into the finest wire, much below one-thousandth of an inch. The tensile strength of the wire increases as the drawing proceeds. The following are average figures from a large number of experiments:—

Diameter in Thousandths of an Inch.	Tensile Strength (Pounds per Square Inch).			
	Tungsten Wire.		Molybdenum Wire.	
5·0	460,000	490,000	200,000	260,000
2·8	480,000	530,000	230,000	270,000
1·5	550,000	600,000	270,000	310,000
1·2	580,000	610,000	...	...

The density of the tungsten and molybdenum also increased with the working, as seen in the following table:—

Diameter in Thousandths of an Inch.	Tungsten.	Molybdenum.
	Before Drawing.	
	18·81	10·02
	After Drawing.	
	150·0	19·30
	10·0	19·64
	1·5	20·19

The electrical resistivity and the temperature coefficient of the two metals are given in the following table:—

	Resistivity (25° C).	Temperature Coefficient
	Microhms per Cubic Centimetre.	from 0 to 170° C.
Tungsten drawn . . .	6·2	0·0051
„ annealed . . .	5·0	...
Molybdenum drawn . . .	5·6	0·0050
„ annealed . . .	4·8	...

The hardness of both tungsten and molybdenum depend very much upon the amount of mechanical working the metals have undergone and upon the presence of impurities.

Both metals are readily attacked by fused oxidising salts, such as sodium nitrate, potassium hydrogen sulphate, and sodium peroxide. The common acids attack tungsten very slowly, but molybdenum rather steadily.

III.—ALLOYS.

Aluminium-Calcium Alloys.—The results of a research on the electrochemical potentials and electrical conductivity of aluminium-

* *Metallurgical and Chemical Engineering*, June 1910, vol. viii. pp. 340-341.

calcium alloys are given by J. M. Breckenridge* in a paper read before the American Electrochemical Society, May 1910. Since the alloys of the calcium-aluminium series present physical and chemical properties which are different from the original metals, it was thought that this marked change of properties might be due to the presence of one or more chemical compounds, and for this reason a study of the constitution of the alloys of this series was undertaken. The electrochemical potentials were measured in a solution of calcium chloride in ethyl alcohol, since aqueous solutions would have acted on the alloy directly. The potentials were measured against the standard calomel electrode, and a special connection was worked out between the ethyl alcohol solution and the calomel electrode. The electric conductivity of the alloys was simultaneously determined. The curves of potential and of conductivity when plotted as functions of the calcium content of the alloy are quite smooth and regular, with the exception of a distinct break in both curves between 32 and 34 per cent. calcium. The single potential rises suddenly from 0.481 at 32.8 per cent. calcium to 0.912 at 34.3 per cent. calcium, while the conductivity curve, which was falling all the time with increasing calcium content, reaches between 32 and 34 per cent. calcium, a minimum, rises again slightly to a maximum, and then continues to fall. The composition of the alloy, where the break in the two curves occurs, corresponds to the formula Al_3Ca .

This is in agreement with the results obtained by Donski† in the study of the cooling curves of this series.

Analyses of Bolivian Bronzes.—The analysis of a number of ancient weapons and implements found in Bolivia by M. Loeb‡ and S. R. Morey shows that the early workers must have possessed considerable metallurgical skill. The entire absence of silver indicates that the tin was derived from cassiterite, and not from native tin.

	I.	II.	III.	IV.	V.	VI.
Copper	91.81	90.51	95.59	97.43	94.96	91.43
Tin	7.56	8.92	4.48	...	4.98	7.05
Iron	trace	trace	trace	trace	...	trace
Sulphur . . . . .	...	trace	...	little	0.53	...
Arsenic . . . . .	...	...	...	2.14	...	...
Total	99.37	99.43	100.07	99.57	100.47	98.48

No. IV. appears to have been prepared from domeykite, or some other copper arsenide, fairly free from sulphur.

* *Metallurgical and Chemical Engineering*, June 1910, vol. viii. p. 349.

† *Zeitschrift für anorganische Chemie*, vol. lxvii. p. 201.

‡ *Journal of the American Chemical Society*, 1910, vol. xxxii. p. 652.

Copper-Iron-Nickel Alloys.—The alloys of copper, iron, and nickel have been examined by R. Vogel,* who finds that long annealing is necessary to bring about equilibrium, so that microscopical methods are to be preferred to thermal analysis in dealing with them. Alloys containing equal parts of copper and iron consist of two constituents, unless at least 40 per cent. of nickel is present: the quantity of nickel required to produce homogeneity becomes less as either the copper or the iron is increased. Some alloys have a structure, when etched, resembling that of martensite.

Alloys near the middle of the series were often found to yield very spongy castings. Of the homogeneous alloys, those of medium composition are extremely tough, as is seen by the bending of the crystals without breaking under the pressure of the file. All the alloys of the series are magnetic at the ordinary temperature.

Electrical Conductivity of Liquid Alloys.—Very few data exist as to the electrical conductivity of liquid alloys, although this property is of importance in view of the extent to which molten alloys are used as conductors in electrical furnaces, and the knowledge is also required as a means of determining constitution. The first part of an investigation by K. Bornemann† and P. Müller shows that a close parallelism exists between liquid and solid alloys in this respect. The liquid alloys of sodium with potassium have a conductivity curve of the U-form characteristic of a continuous series of solid solutions, whilst molten alloys of lead and tin have an almost rectilinear curve. The temperature coefficients follow a similar course to the conductivities. The presence of a highly dissociated compound, such as Na_3K , is without effect on the curve, but a stable compound, such as NaHg_2 , in the sodium amalgam series, gives rise to a well-defined maximum.

The conductivity of mercury is lowered by the addition of an alkali metal, but is raised by most of the other metals. The conductivity of lead is raised by the addition of tin, zinc, cadmium, antimony, or bismuth, although the conductivity of bismuth is less than that of lead. Both mercury and lead have abnormally low temperature coefficients, and the results are taken to confirm Liebenow's view that liquid mercury is a mixture of simple and complex molecules.

Heterogeneous liquid alloys have a conductivity proportional to the concentration. The conductivity may be used to determine the temperature at which a homogeneous alloy separates into two layers, a sharp kink in the curve being obtained.

Gold-Magnesium Alloys.—A comparison of the results formerly obtained by G. G. Urazoff and by R. Vogel has led to the production of a joint paper by these authors.‡ The results of Urazoff are in the main confirmed, including the existence of a fourth compound, Au_2Mg . The

* *Zeitschrift für anorganische Chemie*, 1910, vol. lxxvii, p. 1.

† *Metallurgie*, 1910, vol. vii, p. 396.

‡ *Zeitschrift für anorganische Chemie*, 1910, vol. lxxvii, p. 442.

transformation to AuMg_2 and AuMg_3 takes place at 716° , as described by Vogel, whose curve representing the change of concentration of the solid solution Au-AuMg with temperature is also confirmed.

Hardness Tests on Alloys of Nickel and Copper with Electrolytic Iron.—The results of hardness tests obtained by means of the scleroscope on alloys made of electrolytic iron with 2 to 20 per cent. of Monel metal are given by G. A. Roush.*

The hardness curve for the forged samples rises rather rapidly up to 10 per cent., and then more gradually to the end of the series. In the annealed samples the rise up to 10 per cent. is not quite so abrupt, and from 10 to 16 per cent. is practically a straight line; from 16 to 20 per cent. the rise is about the same as that below 10 per cent. Curves are given showing the comparisons between the single additions of nickel and copper and their addition together with a view of ascertaining the possibility of substituting the new commercial alloy, Monel metal, for the more expensive nickel, as an addition agent.

In the forged condition the hardness does not reach quite such a high value as might be expected, if the hardening powers of the two metals were additive, but the maximum value is reached at a much lower percentage, so that the small difference in hardness is more than balanced by the economy of the smaller addition. In the annealed samples the hardness is much above anything that could be predicted from the results obtained from the single metals, the difference being particularly pronounced between 8 and 16 per cent. The comparison of the nickel and Monel curves shows several points in favour of the Monel. The maximum available hardness in both the forged and annealed condition, without the addition of excessive quantities of Monel, is at about 11 or 12 per cent. as against 16 per cent. for pure nickel, the maximum values in both cases being about the same. The addition of pure nickel below 6 per cent. gives no appreciable increase in hardness, whilst the addition of the same quantity of Monel metal gives a marked increase in the hardness.

Mercury Telluride.—The thermal analysis of mixtures of mercury and tellurium is found by G. Pellini† and C. Aureggi to indicate the existence of a single telluride, HgTe , which melts with decomposition at about 550° . The combination of mercury with tellurium takes place with development of heat.

Silver-Cadmium Alloys.—The constitution of the alloys of silver and cadmium has hitherto been unknown. It is found by G. Bruni‡ and E. Queregh that these metals form two compounds, AgCd and AgCd_4 , and that solid solutions are formed throughout the series, with the exception of a gap between 80 and 87 atomic per cent. of cadmium. There

* *Metallurgical and Chemical Engineering*, September 1910, vol. viii. pp. 522-523.

† *Gazzetta chimica italiana*, 1910, vol. xl., ii. p. 42.

‡ *Zeitschrift für anorganische Chemie*, 1910, vol. lxxviii. p. 198.

is a general resemblance between this series and the alloys of silver and zinc. There is no eutectic alloy in the series, so that the melting-point of cadmium is raised, and not lowered, by the addition of silver. Certain of the alloys undergo a transformation in the solid state, the nature of which is at present under examination by the microscopical method.

Ternary Alloys.—An elaborate review of the possible types of ternary systems among metallic alloys is given by E. Jänecke,* and the ternary alloys of copper, silver, gold, chromium, manganese, iron, cobalt, nickel, palladium, and platinum are classified under a number of headings in accordance with the character of the binary systems of which they are made up.

IV.—MISCELLANEOUS.

A New Process for the Production of Metallic Coatings:

Spray Process.—An account is given by M. U. Schoop † of his spray process for the production of metallic coatings on articles of various descriptions. In this process the metal, in a liquid and highly heated condition and in a finely subdivided form, is sprayed on to the surface to be coated. The easiest method of subdivision makes use of compressed gases or vapours.

The metal, a coating of which is desired, is melted in a crucible, and is then forced by means of compressed gas so as to leave a nozzle through a capillary opening. Immediately after leaving the nozzle it is acted upon by a stream of gas or vapour of suitable cross section, and is thereby subdivided, so that a metallic disc is produced through which the articles to be coated are passed quickly, the passage lasting from one to three seconds. Either the same or different gases may be used to exert the pressure on the metal and to atomise it. Different metals behave differently when being atomised, the melting-point, degree of fluidity, and the affinity for the gas used being important points. The process may be used for producing alloy coatings, but results so far obtained appear to show that a homogeneous subdivision in the spray and a homogeneous alloy coating can only be obtained when the two metals are mixed in eutectic proportions. Under suitable conditions and with high gas pressures the density of the coating produced is not very different from the density of the metal under normal conditions. It is an interesting fact that the zone of metallic mist is at a comparatively low temperature, being 40° C. to 60° C. only, although the molten metal may have a temperature of several hundred degrees, and although the gas used is also at a high temperature.

The hardness of the metallic films produced by the spray process is greater than the hardness of those produced by other methods. Micro-

* *Metallurgie*, 1910, vol. vii, p. 510.

† *Metallurgical and Chemical Engineering*, July 1910, vol. viii, pp. 404-466.

scopic examination of the coatings produced show that porous places and slag enclosures are absent.

Titanium as a Desulphurising Agent.—Experiments by P. Müller* show that titanium sulphide, Ti_2S_3 , may be prepared by heating rutile with metallic sulphides and carbon, but that the product is not pure, other volatile compounds being also formed. When iron sulphide or nickel matte is heated in an arc furnace with an excess of rutile and carbon, mixtures of carbides are obtained, free from sulphur. Titanium thus expels sulphur at high temperatures.

V.—PHYSICAL PROPERTIES.

Allotropy of Lead.—It has been suspected, from microscopical observations of the crystallisation of lead from solution, that this metal is capable of existing in two allotropic forms. Measurements of the electrolytic potential by E. Cohen† and K. Inouye show that there is no allotropy, but that the two forms differ merely in crystalline habitus.

Effect of Pressure.—Experiments on the influence of pressure on metals by G. Spezia‡ show that when fine filings of copper or silver are subjected to a pressure of 8000 atmospheres for a month at the ordinary temperature, apparently homogeneous blocks are obtained, as described by Spring, but that these blocks consist of strongly adhering particles, no true welding having taken place. When a mixture of copper and silver filings is used, both metals are seen under the microscope to be distinct, and there is no sign of inter-diffusion. This result is not merely due to the insufficient length of time, as an examination of the veins of native silver in the native copper of Keveenaw Point shows that no diffusion has occurred since the formation of the deposit.

The quasi-fluid condition of metals and other crystalline solids produced by severe deformation, as in Spring's experiments, does not result when the pressure applied is uniform in all directions. Plasticity is only observed when the pressure is so applied as to cause flow (through an orifice, for example), and a prism of metal, subjected to external pressure uniform in all directions, has no tendency to become spherical.

Hardness and its Measurement.—A comparison is made of the hardness data and other physical tests on the alloys of nickel, copper, and Monel metal with electrolytic iron by G. A. Roush.§ Diagrams are given of these materials containing hardness curves along with curves showing ultimate stress, elasticity, reduction of area, and elongation of the same specimens. The hardness curve roughly approximates the general

* *Metallurgie*, 1910, vol. vii. p. 537.

† *Zeitschrift für physikalische Chemie*, 1910, vol. lxxiv. p. 202.

‡ *Atti R. Accad. Sci. Torino*, 1910, vol. xlv., ii. p. 525.

§ *Metallurgical and Chemical Engineering*, October 1910, vol. viii. pp. 578-581.

direction of the curve for the elastic limit, but in many points there is a wide difference. A comparison of the hardness curves with those of elongation and reduction of area show that it is the ductility of the material that causes the greater part of the variation of the hardness and elastic limit curves. Since the difference between the elastic limit and ultimate strength depends to a certain extent on the ductility of the material, it is probably more nearly correct to compare hardness with ultimate strength rather than with elastic limit. While the results point to the existence of a definite relation between hardness and elastic limit or ultimate stress, this relation is of a very complicated nature and requires further data to determine its exact nature.

Hardness of Alloys of Nickel and Copper with Electrolytic Iron.—The results of determining the hardness of alloys of nickel and copper with electrolytic iron by means of the Shore scleroscope are given by G. A. Roush.* In the nickel-iron alloys, the curve of hardness with increasing nickel content for the forged specimens is concave up to 7 per cent. nickel and lies slightly below the value found for pure iron. From 7 to 11 per cent. there is a rapid rise to a maximum, dropping off slightly to 19 per cent., and then a rapid drop up to 25 per cent. to about the value of pure iron, where it remains practically constant. In the annealed condition the curve starts at about the value for pure iron, rising gradually to 10 per cent., then abruptly to a maximum at 16 per cent., followed by a sharp decline up to 32 per cent., and then remains practically constant at a value slightly higher than that of pure iron. From 21 to 30 per cent. the curve for the annealed samples lies above that for the forged samples. In the copper-iron alloys for the forged condition up to 1.5 per cent. of copper the hardness curve is concave and lower than that of pure iron. From 1.5 to 2.5 per cent. it proceeds in a straight line, and from 2.5 per cent. there is a continued rise. In the annealed condition, the hardness increases in a straight line with only a very slow rise throughout the series.

The nickel and copper alloys in the range studied are exceptions to the law of hardness formulated by Kurnakoff † and Zemezuzny, for, in the iron-nickel alloys, although solid solutions are formed throughout the series, the maximum hardness is between 10 and 20 per cent., and does not coincide with the maximum electrical resistance which occurs at 30 per cent., as it should do in accordance with above law. In the iron-copper alloys the point of maximum hardness should occur at 1.5 per cent. copper, followed by a straight line beyond 3.5 per cent., because the metals are present as a mechanical mixture beyond this point.

Internal Friction of Solids at Low Temperatures.—In all metals studied by C. E. Guye ‡ and V. Fredericksz it was found that the decrement of internal friction increased very rapidly with a rising

* *Metallurgical and Chemical Engineering*, August 1910, vol. vii, pp. 468-470.

† *Journ. Russ. Phys. Chem. Ges.*, 1908, vol. xl, p. 1067.

‡ *Revue de Métallurgie*, January 10, vol. vii, pp. 85-86.

temperature, as though all, or at least a portion, of that friction was due to the presence of an increasingly large number of free particles capable of causing friction with one another, or with fixed molecules in the mass. This being so, it was reasonable to suspect that the internal friction might be a property which would tend to disappear in proportion as absolute zero was approached, or, in other words, a more perfect solid condition was attained to. Experiments were made, but they showed that while, generally speaking, a considerable diminution in the internal friction occurred, the phenomena involved are much more complex. The appliance used in the experiments is described and illustrated, and a table is given showing the coefficient for internal friction ascertained at temperatures of 100° , 50° , 0° , -80° and -196° respectively, for silver, aluminium, gold, magnesium, iron, and quartz. It was found that the coefficient decreases as the temperature falls, in the case of silver, aluminium, and iron: in the case of aluminium the coefficient is 27.4 times lower at liquid air temperature than at that of boiling water. In the case of magnesium and gold the coefficient falls until -80° is reached, after which it rises again, at -196° . In the case of metals it was found that the modulus of elasticity increases as the temperature falls, but in the case of quartz the reverse takes place.

Interstrain Disease in Tin.—Observations and experiments have been carried out by E. Cohen * with a view to elucidating the cause of certain unhealthy conditions occurring in tin. The results showed that the phenomena described by von Hasslinger under the name of "tin pest" may be attributed to the mechanical work undergone by the metal, which causes it ultimately to disintegrate into powder. To this ailment it is now proposed to give the name "interstrain disease." Its spread is accelerated not only by increased temperature but also by "inoculation" or "infection," and may appear, even at normal temperatures, soon after having been subjected to the infection. It can be transmitted both mechanically and physically as well as chemically. It is due to a condition of metastability in one part of the metal as compared with another.

Manganese Bronzes and their Elastic Limit.—J. A. Capp † deals with the elastic limit of manganese and other bronzes with the object of showing that whilst the yield point for steel is so well marked in properly conducted tests, and bears a sufficiently definite relation to the true elastic limit to warrant the dependence placed upon it by the engineer, there is no equally well-defined point found in testing bronzes, and the value commonly obtained from rapid commercial tests as the elastic limit or yield point on bronze may be quite misleading. Tabulated results are given of tests made on various samples of cast manganese bronze.

* *Revue de Métallurgie*, April 10, vol. vii. p. 240.

† *Journal of the American Society of Mechanical Engineers*, vol. xxxii. pp. 373-384.

Occlusion of Gases contained in certain Copper Alloys.—

G. Guillemin* and B. Delachanal give details of an interesting research on occluded gases occurring in certain alloys of copper, also in tin. The observations show that forged brass contains an important amount of hydrogen, carbon dioxide, and carbon monoxide in the occluded state. In sound pieces the occluded gas is almost entirely (more than 90 per cent.) composed of hydrogen. In the case of unsound castings the hydrogen is accompanied by an important proportion of carbon monoxide and a little carbon dioxide. Bars that are "chill cast" contain less gas than those that are cast in the ordinary way. The presence of occluded hydrogen, when occurring even in large proportions in sound metal, does not appear to have a deleterious effect on the mechanical properties of brass. Phosphor-bronzes retain very little occluded gas, this consisting chiefly of carbon dioxide and hydrogen. Phosphorus appears to diminish the solubility of hydrogen in the phosphor-bronze alloys, just as it does in the case of cast iron and steel. With regard to commercial tin, whether in ingots or granulated, the metal contains a slight amount of gas consisting of carbon dioxide, hydrogen, and carbon monoxide. The metals and alloys which the authors examined, provided that they were free from blowholes, did not give rise to the "spitting" phenomenon associated with the cooling of silver, cast iron, &c. The occluded gases were extracted only by heating the alloys to their melting-point in a vacuum, or at least in a highly rarefied atmosphere.

Reflecting Power of Metals.—The results of the examination of the optical properties of various metals, more especially those used in incandescent lamps, are given by W. W. Coblentz.† The fact that all pure metals have a low reflecting power in the ultra-violet and in the visible spectrum has been verified. In the experiments, a fluorite prism, a mirror spectrometer, and a new vacuum bolometer were used. The metal was compared with a new silvered glass mirror of which the reflecting power was known; a Nernst glower was used as a source of radiation. The results obtained are in excellent agreement with those of Wartenberg.‡

The reflectivity of tungsten is found to rise abruptly from a low value of 50 per cent. in the yellow to 89 per cent. at 2.5μ , beyond which point it increases gradually to 96 per cent. at 10μ . This is characteristic of pure metals. Molybdenum shows a reflectivity of 46 per cent. in the yellow which rises to 85 per cent. at 2.5μ , beyond which point it gradually increases to 95 per cent. at 10μ . The reflectivity curves of molybdenum and tungsten are so nearly alike that from a consideration of their emissivities and luminous efficiencies, there seems to be no great choice in the use of these two metals in incandescent lamps. On the other hand, from a consideration of their physical properties, the molybdenum filament would be preferable because of its toughness and its ductility.

* *Comptes rendus*, November 1910.

† *Journal of the Franklin Institute*, September 1910, vol. clxx, pp. 169-192.

‡ *Verhandlungen Deutsche Physikalische Gesellschaft*, 1910 vol. xii, p. 105.

in contrast with tungsten, which is very brittle. It is principally a question of overcoming certain physical weaknesses in the molybdenum to make it practical. The reflectivity of samples of natural graphite was 23 per cent. in the yellow, gradually increasing to 63 per cent. at 10μ , hence the graphitised carbon filament cannot have the same luminous efficiency as the tungsten lamp at the same temperature, although it has a higher emissivity in the visible spectrum. The reflectivity of tantalum rises abruptly from 39 per cent. in the yellow to 85 per cent. at 2μ , beyond which point the rise is gradual to 94 per cent. at 9μ . In the abrupt rise of reflectivity tantalum, zinc, and silver stand unique among the metals. For antimony, the reflectivity rises from 53 per cent. in the yellow to 72 per cent. at 9μ . Details are also given of the reflectivity of rhodium, iridium, iron, magnesium, chromium, vanadium, tellurium, and silicon.

Solubility of Oxygen in Molten Silver.—The solubility of oxygen in molten silver has been studied by F. G. Donnan* and T. W. A. Shaw, who point out that the question possesses both a technical and a scientific interest. From a technical point of view the "spitting" of the silver in the moulds during a pour, and the liability of the ingot to "blister" on rolling, due to entangled oxygen, are important, and from a scientific point of view the molecular condition of the oxygen dissolved in the silver is interesting. The apparatus designed to measure the solubility at pressures equal to and below atmospheric pressure is described, but details of only two determinations are given, as after these were completed, results were published by Sieverts† and Hagenacker which covered the grounds of the research. The results given show that the volume of oxygen absorbed by 10 grammes of silver at 1020°C . and 751 mm. pressure was 20.5 cubic centimetres, and at 1020°C . and 753 mm. pressure 20.2 cubic centimetres. These results agree very well and are in close agreement with those obtained by Sieverts and Hagenacker. The latter results are shown in the following table:—

Solubility of Oxygen in Molten Silver at 1075°C .

Oxygen Pressure in Millimetres (P).	Oxygen absorbed by 10.87 Grammes of Silver (m).	P m	\sqrt{P} m
1203	26.91	44.7	1.29
760	21.01	...	1.31
488	17.02	...	1.30
346	14.53	23.8	1.28
209	11.75	...	1.23
150	10.09	...	1.21
128	8.87	...	1.28
39	4.75	8.2	1.31

* *Journal of the Society of Chemical Industry*, August 31, 1910, vol. xxix, pp. 987-989.

† *Zeitschrift für physikalische Chemie*, 1909, vol. xlviii, p. 115.

From the above results it is evident that the concentration of the oxygen in the molten metal is proportional to the square root of the oxygen pressure, and from this may be deduced the fact that the oxygen must be present as physically dissolved atomic oxygen or as dissolved silver monoxide. If the oxygen were present as dissolved diatomic molecules, then, from Henry's law, the concentration of the dissolved oxygen would be proportional to the pressure. The assumption that the oxygen exists in the silver as dissolved silver monoxide cannot be disproved by the fact that silver monoxide would exert an enormous oxygen dissociation-pressure at temperatures near 1000° C., for it will be present as a dilute solution, and the spitting of silver would be due to the fact that during the solidification of the silver, the silver monoxide would be thrown out of solution and explosively dissociate.

The solidified silver appeared to adhere strongly to the silica bulb in which it had been heated, and this may possibly be due to a reaction between the silica and dissolved silver monoxide. From the figures given above, it is calculated that 1 kilogramme of silver would dissolve at the melting-point 1100 cubic centimetres of oxygen, which would require 10 grammes of aluminium for its deoxidation.

Special Bronzes and their Coefficients of Equivalence.—

L. Guillet* and L. Révillon have investigated the coefficient of equivalence in certain zinc bronzes with the object of ascertaining the influence of foreign elements on copper-tin alloys. On microscopically examining bronzes in which gradually increasing quantities of zinc have been substituted for a portion of the tin, while the proportion of copper has been maintained constant, it may be seen that the constituent δ continues to exist below the limits assigned as the values of the solubility of tin in copper, and that the appearance of the alloy is always that of one containing a higher percentage of tin than analysis shows actually to be the case. In order to ascertain what the action of zinc is on the constitution of bronzes, it seems reasonable to estimate its coefficient of equivalence by the same method as that used to ascertain the equivalence of the metals introduced into special brasses. Thus, in any one sample there may be obtained, by chemical analysis, the real figure, while another, or "fictitious" figure, may be obtained by microscopic examination, on observing the areas occupied by the constituent δ and comparing their degree of importance with that of samples carefully standardised. The coefficient of equivalence sought can then be obtained by the following formula—

$$C = 1 + \frac{(A - A')100}{qA'}$$

in which A is the actual percentage of copper, A' the "fictitious" percentage, and q the amount of zinc present after analysis.

Temperature Coefficient of Resistance of Copper.—The results of experiments to determine whether the temperature coefficient

* *Revue de Métallurgie*, June 10, vol. vii pp. 429-432.

of different samples of copper does vary, and also to find whether there is any simple relation between the conductivity and the temperature coefficient, are given by J. H. Dellinger.* The results have shown that there are variations of the temperature coefficient, and that the relation of conductivity to temperature coefficient is practically a simple proportionality. Thus annealing and the presence of varying amounts of chemical impurities were found to cause a proportional variation in these constants. The effect of bending and winding wires was also investigated.

Any distortion of an annealed wire produces local hardening and increase of resistance; it was shown that much the greater part of this increase was due to local changes of cross section and not to change of resistivity. This was shown by the fact that while the apparent conductivity decreased, the temperature coefficient changed practically not at all. The main result of this investigation may be expressed in the form of the following practical rule:—The 20°C . temperature coefficient of copper is given by multiplying the number expressing the per cent. conductivity decimally by 0.00394.

This rule can be put in a convenient form for reducing the results of conductivity measurements to a standard temperature, for the change of the resistivity per degree C. of a sample of copper is 0.000598 ohm per metre gramme, or 0.00681 micro-ohm per centimetre cube. These last two constants are independent both of the temperature of reference and of observation, and also independent of the sample of copper. It is pointed out that in certain cases the measurement of temperature coefficient has considerable advantage over a conductivity measurement. For example:—(1) Odd shapes; (2) short samples; (3) distorted or bent wires; (4) in the estimation of chemical purity.

Thermo-Electric Properties of Alloys.—W. Broniewski † points out that the thermo-electric properties of alloys have been much less studied than many of their other electrical properties, such, for instance, as conductivity, and electromotive force of solution. He briefly reviews the work of the earliest investigators, and gives an account of his own researches on the influence of solid solutions on thermo-electric properties, and gives curves showing the fundamental considerations involved. The alloys specially illustrated are those of gold-silver, copper-nickel, bismuth-antimony, silver-platinum, silver-palladium, platinum-rhodium, platinum-iridium, steel alloys; bismuth lead, tin, and cadmium; tin lead, cadmium, lead-cadmium; copper-cobalt, cadmium-antimony, and copper-aluminium. A bibliography of the subject is appended.

The Strength of the Alloys of Electrolytic Iron and Monel Metal.—The results of tests on the strength of alloys of electrolytic iron with nickel, copper and nickel, and copper, are given by C. F. Burgess ‡ and J. Aston. The general conclusions for the iron-nickel

* *Journal of the Franklin Institute*, September 1910, vol. clxx, pp. 213–216.

† *Revue de Métallurgie*, May 1910, vol. vii, pp. 340–368.

‡ *Metallurgical and Chemical Engineering*, August 1910, vol. viii, pp. 452–456.

alloys are as follows:—1. With increase of nickel there is an increase of strength, with a slight decrease of ductility in the range of lower nickel content. 2. Beyond this range the addition of nickel causes a sudden increase of strength with a marked decrease of ductility over a zone of decided brittleness. 3. The position of the brittle zone varies with the carbon content, and probably with a variation of other impurities. For a pure alloy the area may be set between 10 and 16 per cent. nickel. 4. Accompanying this brittleness there is a marked hardening of the material. 5. Annealing has a tendency to confine the range to more narrow limits. 6. For percentages of nickel above those of the zone of brittleness there is a restoration of the ductility and softness.

The results of the tests on iron-copper alloys, in the absence of carbon unannealed samples, show a successive increase of tensile strength up to the maximum copper addition of 7 per cent. (the limit of forgeability). The yield point was close to the ultimate strength, and the elongation fell off with regularity. Brittleness was therefore the accompaniment of the copper additions, and increased with the percentage present. Annealing had a most marked effect, lowering the ultimate strength and elastic limit throughout, but especially for copper percentages above 1. The elongation became very good throughout the entire range. The results already given suggested a research on the effect of nickel and copper when alloyed together with electrolytic iron, and as the alloying metal, Monel metal was used. The analyses of two samples of Monel metal were:—Nickel, 66.90 and 67.96; copper, 24.35 and 26.00; iron, 5.00 and 2.80; manganese, 2.18 and 1.62. From 2 to 12 per cent. of alloying metal the ingots forged readily from 12 to 18 per cent.; high temperatures were necessary for forging, and with 18 to 20 per cent. a white scintillating heat was necessary. Up to 12 per cent. addition, the bars were machined in the lathe; above this, grinding was resorted to, the material being too hard for efficient working with lathe tools.

In the unannealed condition, from 0 to 8 per cent. addition, there is a rather rapid rise in the ultimate strength and elastic limit; the latter rises more rapidly, however, and at 8 per cent. the elastic ratio is 0.85, indicating brittleness. This is confirmed by the falling off in the values of elongation and reduction of area. Up to 4 per cent. of Monel addition there is an increase in ductility.

From 8 per cent. upwards there is a rapid increase in maximum strength and elastic limit, but with increasing brittleness. Annealing has but little effect on the properties of the alloys with low Monel additions; for those alloys containing 4, 6, and 8 per cent., the strength is higher; with 10 per cent. addition the tests showed—ultimate strength, 150,000 pounds per square inch; yield point, 144,400 pounds per square inch; elongation, 15.7 per cent. on 2 inches; reduction of area, 51.9 per cent. Between 10 and 20 per cent. addition, the ultimate strength shows but little variation, while the elastic limit becomes less with increasing additions.

The Thermo-Electric Behaviour of Certain Binary Alloys.—

The thermo-electric behaviour of a number of binary alloys of known composition has been determined by E. Rudolfi,* using rods prepared by drawing up the molten alloy into smoked glass tubes. The rods were then measured against copper and nickel at 150° and 100°. The curves showing the variation of thermo-electric power with composition have the same form as the corresponding curves of electrical conductivity, alloys containing the two pure components, such as tin and zinc, giving a straight line; isomorphous pairs like silver and gold giving a U-shaped curve; and alloys forming solid solutions to a limited extent, such as lead and antimony, a broken curve. For thermopiles, in which a high thermo-electromotive force is required, the best results would be obtained from metals forming solid solutions with one another.

Transformation Points of Copper-Aluminium Alloys.—

The constitution of the copper-aluminium alloys is but imperfectly understood; only those containing from 8 to 16 per cent. of aluminium have been studied. According to L. Guillet, such alloys show two transformation points—one, clearly marked, at about 500°, which falls slightly as the percentage of aluminium increases; and the other, not usually very clearly marked, at about 750°. The transformation points on cooling are, generally speaking, higher than those which occur on heating. On the other hand, Carpenter and Edwards have established totally opposite conclusions. Maurice Barrie† has now endeavoured to elucidate the study by investigating the variation in the electrical resistance of copper-aluminium alloys with variations in temperature. He used bars 15 millimetres square and 11 centimetres long, and the method employed in ascertaining the relative values of the resistances was the same as that adopted by Boudouard in his researches on the allotropic modifications of steels. Details of the apparatus employed and of the precautions to be observed are given, together with curves showing the results obtained, and tables collating those results. The conclusions derived from a study of the curves are as follows:—In aluminium bronzes containing 8 to 15·5 per cent. of aluminium, three transformation points occur—one at 200°, one at about 500°, and one at about 750°. The second transformation point, occurring at 500°, is very clearly marked, and in all cases the temperature of the transformation on cooling is below that of the transformation on heating. This agrees with the results obtained by Carpenter and Edwards, and conflicts with those found by Guillet. Repeated heatings have little real effect except to render the curves more distinct, probably because the alloy tends to become more homogeneous.

* *Zeitschrift für anorganische Chemie*, 1910, vol. lxvii. p. 65.

† *Revue de Métallurgie*, January 10, vol. vii. pp. 16-33.

ANALYSIS, TESTING, AND TEMPERATURE MEASUREMENT.

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I.—ANALYSIS.

Accuracy of the Gold Bullion Assay.—The probable error of gold bullion assays, as conducted at the U.S. Treasury Mint, having been reported by F. P. Dewey as considerably greater than that found by T. K. Rose in 1893, the results obtained in the Royal Mint have now been discussed by J. Phelps.* Gas muffles and patent magnesia cupels are now used, although almost equally good results may be obtained with good bone-ash cupels. In the routine work of the Royal Mint the average probable error of the surcharge is ± 0.167 per 1000. The probable error of a single assay is ± 0.040 ; and after applying the surcharge, ± 0.043 per 1000. In the assay of trial plates, an accuracy of ± 0.01 may be claimed for the mean of any considerable number—twenty or more—of assays. This could not be reduced by increasing the accuracy of weighing beyond its present limit of 0.025 milligram. Fine gold received from the Utrecht Mint in 1907 assayed 999.980 fine. The probable error of the U.S. Mint assays is much higher, being not less than ± 0.150 per 1000 on a single assay. The probable error of the London trade assayers appears to be about ± 0.081 on a single assay, as shown by a comparison of their assays with those of the Mint.

Analysis of Manganese Bronze.—A method for the complete analysis of manganese bronze is given by H. B. Swan.† The method consists of dissolving the alloy in nitric acid (1 to 1), filtering off and weighing the residue for tin. The filtrate is evaporated with sulphuric acid to get rid of nitric acid and to separate lead if present. The copper is deposited from a measured quantity of the filtrate by electrolysis. Two determinations of copper are made, and the resulting solutions are used

* *Transactions of the Chemical Society*, 1910, vol. xcvi. p. 1272.

† *Metallurgical and Chemical Engineering*, August 1910, vol. vii. pp. 463-464.

for estimating iron and alumina respectively. The alumina is weighed as phosphate, and the iron determined volumetrically with potassium permanganate solution. The manganese and zinc are determined in separate quantities of the copper solution, the copper being separated by aluminium or by electrolysis. The manganese is determined by the bismuthate method, and the zinc either as pyrophosphate or by electrolysis. The method outlined above is said to give excellent results and to be comparatively rapid, six to seven hours being required for the complete analysis.

Analytical Methods.—Heinrich Biltz* and Otto Hödtke show that ferric iron is precipitated quantitatively, even from a strongly acid solution, by a 6 per cent. solution of ammonium "cupferron" (nitrosophenyl-hydroxylamine). The separation from nickel, aluminium, and chromium is quantitative. The same reagent precipitates copper, but to obtain exact results the solution should not contain a large excess of mineral acid. An excess of the reagent precipitates the copper quantitatively from acetic acid solution. Cadmium and zinc do not interfere, but mercury, lead, tin, and silver are precipitated.

To separate iron and copper, the mixed precipitate with "cupferron" is washed with ammonia, which dissolves the copper. The filtrate is evaporated and the copper weighed as oxide after ignition. The residue is converted into ferric oxide by ignition.

Assay of Tin Ores.—The various methods of assaying tin ores are discussed by J. Gray,† and the results of a number of experiments are given.

The causes of inaccuracies of the dry assay are given, and then the methods of effecting solution of tin ores are discussed, and the author's conclusions regarding these methods are as follows:—

1. The passage of a current of hydrogen over the finely powdered ore heated to redness, by which means the cassiterite is reduced to metallic tin, which is dissolved in hydrochloric acid. The uncertainty which exists as to whether all the oxide has been reduced necessitates a re-treatment of the residue in hydrogen or a fusion.

2. Heating the finely powdered ore with zinc dust in a porcelain crucible and extraction of the reduced tin with hydrochloric acid. Very satisfactory results were obtained by this method, which is also very rapid.

3. Treating a mixture of the finely powdered and zinc dust with dilute hydrochloric acid. This method is unsatisfactory, as some varieties of cassiterite are more soluble than others.

4. Heating the ore with sodium carbonate and sulphur, extraction with water, and precipitation of tin sulphide with acid. A re-fusion of the residue is also necessary in this case, and the method is tedious.

* *Zeitschrift für anorganische Chemie*, 1910, vol. lxvi, p. 426.

† *Journal of the Chemical, Metallurgical, and Mining Society of South Africa*, March 1910, vol. x, pp. 312-315.

5. Fusion of the ore with potassium cyanide, extraction of the soluble portion with water, and solution of the residue in hydrochloric acid. The loss of tin as alkali stannate is one objection to this method, and the results are unsatisfactory.

6. Fusion with caustic alkalis and acidifying dissolved melt with hydrochloric acid. This method is very satisfactory, but the time necessary for solution is an objection.

7. Fusion with sodium peroxide, extraction with water, and solution in hydrochloric acid. This was found to be the most satisfactory method, ten minutes being the maximum time required to effect a complete solution of the ore.

8. Hallet's method: Fusion of the ore with potassium hydrogen fluoride, extraction with sulphuric acid, and precipitation as metastannic acid by dilution and boiling. The author did not experiment with this method, which does not appear to show any advantages over those previously mentioned.

After solution is obtained, either gravimetric or volumetric methods may be used. Gravimetric methods are unsatisfactory owing to precautions necessary due to presence of other metals.

Of volumetric methods, the ferric chloride and iodide methods are discussed. The ferric chloride method was not so satisfactory in presence of arsenic.

The author found the iodide method very satisfactory, and determined the effect of the following impurities:—Arsenic, up to 37.87 per cent.; antimony, up to 35.71 per cent.; bismuth, up to 21.31 per cent.; molybdenum, up to 33.3 per cent.; tungsten, up to 41.6 per cent.; titanium, 15 per cent.

The effect of these impurities was found to be negligible. A bibliography of references to the methods of effecting solution of cassiterite is given.

Determination of Antimony.—An abstract is given of E. G. Beckett's* doctoral thesis, on the degree of accuracy obtainable in the various methods in use for the exact determination of antimony.

The work includes the preparation and analysis of pure antimony trisulphide and the determination of antimony as trisulphide, volumetrically with iodine solution, as tetroxide and as pentoxide.

The author's conclusions may be summarised as follows:—

1. The most accurate method of determining antimony is by precipitation as trisulphide and weighing as such. The method of Vortman and Metzl is preferable to that of Henz from its greater convenience and degree of accuracy.

2. Antimony trisulphide precipitated from hydrochloric acid solutions always contains chlorine, which cannot be removed by washing. The amount of chlorine is greatly reduced by heating the precipitate to

* "Inaugural Dissertation." By E. G. Beckett, Zürich, 1909. Gebr. Leeman & Co., Zürich.

300° in a stream of carbon dioxide, after which the antimony trisulphide generally contains from 0.15 to 0.3 per cent. chlorine.

3. The volumetric determination of antimony with iodine gives very concordant results, but these are only correct when the older atomic weight of antimony (122) is used. When the atomic weight is taken as being 120.2, the results are about 1 per cent. too low.

4. The determination of antimony as tetroxide is unreliable when a blow-pipe is used for the ignition. The method may give good results if the oxide is heated in a furnace giving a uniform temperature of 800° to 900° C., but means have to be adopted to prevent the absorption of hygroscopic moisture during the process of weighing.

5. The determination of antimony as pentoxide is not reliable.

Determination of Sulphur in Brass and Bronze.—A method for the determination of sulphur in brass and bronze is described by G. Thurnauer* in which he has adapted the method used for the determination of sulphur in organic compounds.

Fine filings are taken and passed through a 100-mesh sieve. One gramme is thoroughly mixed with 6 grammes of a mixture consisting of 2 parts of potassium chlorate and 1 part of sodium carbonate.

In a wrought-iron crucible there is first placed a small quantity of sodium carbonate to cover the bottom, then the above mixture is placed in and the whole covered with a little potassium chlorate and sodium carbonate mixture. The crucible is covered and then heated over a Bunsen burner first slowly and then to a fairly high temperature.

The cooled fusion is digested with hot water and solution filtered. The solution is neutralised with ammonia, acidulated with hydrochloric acid, and the sulphur precipitated by means of barium chloride.

Determination of Zinc by Weighing as Sulphate.—A method for the determination of zinc as sulphate is described by E. C. Sullivan† and W. C. Taylor, which is similar to that used in the determination of cadmium, cobalt, and calcium as sulphate. The zinc is first precipitated as sulphide from a hot solution slightly acid with sulphuric or hydrochloric acid. The precipitate thus obtained is readily filtered and washed with hot water. The precipitate is washed into a deep beaker with as little water as possible and dissolved in hydrochloric acid. The solution is boiled until free from sulphuretted hydrogen and then transferred to a weighed porcelain crucible and evaporated on a water bath after the addition of only a little more sulphuric acid than the quantity required to form zinc sulphate. The evaporation is completed in a hot air bath and the crucible then heated over a Bunsen burner to a full red heat. Crucible then cooled in a desiccator and weighed. Results are accurate to 1 or 2 tenths of 1 per cent.

Lead Estimation.—Minute quantities of lead, as in the air of lead-works, may be estimated by a calorimetric method described by A. G.

* *Journal of Industrial and Engineering Chemistry*, vol. ii. No. 6.

† *Ibid.*, vol. i. No. 7..

Vernon Harcourt.* Hydrogen sulphide is passed into the solution, to which sodium acetate and sugar have been added, and the colour is compared with standard tubes, the preparation of which is described.

Portable Laboratory for the Assay of Minerals.—A. Braby † describes a collection of apparatus and reagents suitable for a portable laboratory for assays. Various forms of small muffle furnace for cupel assays are described and a method given for estimating the weight of a button of gold or silver, after cupellation, by means of a microscopic examination. For this purpose the button is flattened to a uniform and standard thickness in a specially constructed steel mortar, and subsequently placed on a field ruled in small squares. On ascertaining by this means the superficial area of the flattened button, a very close approximation of the weight can be obtained.

Rapid Electro-Analysis.—A paper on a comparison of rapid electro-analytical methods by F. C. Frary ‡ and A. P. Peterson deals with the determination of copper. Rapid electro-analytical methods depend on some process of stirring the electrolyte and bringing continually free electrolyte to the cathode. They differ by the special method of stirring employed. The following three methods were compared: Magnetic rotation of the electrolyte with a gauze cathode (Franz); rotating spiral anode and dish cathode (Smith); simple use of platinum-gauze cathode without rotation (Stoddard), this latter depending on evolved gases and convection currents for the necessary agitation. The authors used as electrolyte a copper sulphate solution with addition of as small a quantity of nitric acid as possible.

From a large number of determinations the authors conclude that, in the case of copper, precipitation by the rotating anode is complete and satisfactory in a few minutes less than with magnetic rotation. Precipitation with magnetic rotation is complete and satisfactory in a little shorter time than when no rotation is used. In the latter case, however, the character of the precipitate is much more variable, and often for no apparent reason the deposit becomes unweighable. Possibly with a little more nitric acid the deposit would have been improved. In all cases the solution should be heated to 70° C. before electrolysis, the heat evolved by the current maintaining this temperature during the process.

Rapid Electro-Analysis with Stationary Electrodes.—Details are given by A. P. Ford § of the rapid methods of electro-analysis as used in the Crane Valve Company, Bridgeport, Conn. (Stoddard's method). Gauze cathodes are used in the form of a cylinder $1\frac{1}{4}$ inch in diameter and $1\frac{1}{4}$ inch in length, made of 52-mesh platinum wire gauze. At each end of the cylinder the gauze is folded over a platinum

* *Transactions of the Chemical Society*, 1910, vol. xcvii, p. 841.

† *Bulletin de la Société de l'Industrie Minérale*, vol. xi, pp. 297-376.

‡ *Metallurgical and Chemical Engineering*, June 1910, vol. viii, p. 349.

§ *Ibid.*, May 1910, vol. viii, p. 229.

wire 0.02 inch in diameter, and the whole soldered to a platinum wire stem about 0.05 inch in diameter and 6 inches long, the cylinder complete weighing about 10 grammes. The anode consists of a platinum wire 0.05 inch in diameter, spiral with seven or eight turns in a length of $\frac{3}{4}$ inch, with enough extra wire to make a straight stem 2 or 3 inches long. The outside diameter of the spiral is $\frac{5}{16}$ inch. The commencement of the deposition is made with a current of four amperes, which is increased to five or six for the last few minutes, and the time allowed is thirty minutes. The deposition of the copper from 1 gramme of brass, &c., is made in a volume of 60 or 70 cubic centimetres, the electrolyte generally containing 5 cubic centimetres of concentrated sulphuric acid and 0.5 cubic centimetre of strong nitric acid. The temperature is nearly or quite at the boiling-point. The method is equally advantageous in the determination of nickel.

Separation of Tin and Antimony.—It is shown by W. Plato* that tin and antimony may be completely separated by distillation, if the tin is fixed by the addition of phosphoric acid. The boiling-point of the mixture is raised by the addition of sulphuric acid, and the necessary current of gas is provided by dropping fuming hydrochloric acid into the flask from a tap-funnel. The whole of the antimony chloride is distilled over at 155°–165°. The tin may now be distilled from the residue by adding more sulphuric acid, running in a solution of bromine in hydrochloric acid, and distilling in a current of carbon dioxide. The tin is present in the distillate as stannic chloride. When arsenic is also present, it is advisable to distil arsenic and antimony together, and then to re-distil the contents of the receiver in a current of carbon dioxide, after adding tartaric acid, when arsenic passes over alone. Lead and copper may be estimated in the residue finally remaining in the flask.

Silver Estimation.—Very minute quantities of silver (down to 0.00004 gramme per litre) may be detected and estimated, according to G. S. Whitby,† by adding cane-sugar to the solution, heating, and then adding sodium hydroxide. A dark coloration is produced, owing to the formation of colloidal silver, and may be compared with that given by a standard silver solution.

The Chemist in the Brass Foundry.—The advantages of employing chemists in brass foundries are detailed by W. M. Corse‡ in a paper presented at the March Meeting of the Chicago Section of the American Chemical Society. These include the proper control of furnace charges, composition of resulting alloy and control of furnace losses; the examination of raw materials for purity; the examination of refractory materials, moulding sands, &c.; and the examination and analysis

* *Zeitschrift für anorganische Chemie*, 1910, vol. lxviii. p. 26.

† *Ibid.*, vol. lxvii. p. 62.

‡ *Metallurgical and Chemical Engineering*, May 1910, vol. viii. pp. 265–266.

of fuels, solid or liquid. The chemist should also have control of experimental work, and should record the results of all tests made, whether they are chemical, physical, or practical tests of material.

II.—TESTING.

Metallurgical Microscope.—A simple and inexpensive metallurgical microscope is described,* which is sufficient for all the usual work of a metallographist, and which has been developed by the firm of Leitz with the aid of W. Campbell. The microscope may be mounted for laboratory research, fitted with a new opaque illuminator in connection with a specially designed illuminating stand which ensures an even illuminated field with the most powerful objectives. The microscope may be arranged for the examination of large metal surfaces and castings at the works. In this case the stage of the microscope with rack and pinion is omitted, and the tube with coarse and fine adjustment is attached direct to the horseshoe stand.

Photomicrographic Apparatus.—A description† is given of a new photomicrographic plant under the name micro-metallograph, developed by Leitz. The construction embodies the principle first applied by Le Chatelier, with certain improvements suggested by W. Guertler and W. Campbell, the object being placed upon the stage whilst the objective is underneath. In the act of focussing, the stage moves together with the object, whereas the objective and illuminating system remain stationary. A fully illustrated description of this new apparatus is given in the article.

III.—TEMPERATURE MEASUREMENT.

Graphic Recorder for Cooling Curves.—An instrument especially designed for studying the cooling curves of iron and iron alloys, but also suitable for certain non-ferrous metals, is described by C. B. Thwing.‡ The method is similar to the well-known difference methods in general use. Two galvanometers are used mounted side by side and recording on a single chart. One galvanometer is attached to a thermo-couple imbedded in the specimen in close contact with the metal of the neutral body. The other galvanometer measures the electro-motive force of a series of short thermo-couples, one set of the junctions of which is imbedded in the neutral body, the other set of junctions similarly imbedded in the test-piece.

* *Metallurgical and Chemical Engineering*, October 1910, vol. viii, p. 603.

† *Ibid.*, August 1910, vol. viii, pp. 503-504.

‡ *Ibid.*, June 1910, vol. viii, pp. 367-368.

High-Temperature Gas Thermometry.—The present limitations of high-temperature gas thermometry are considered by A. L. Day.* The first limitation to the upward extension of the gas scale is a direct result of the choice of a gas. Hydrogen was first used, but it has since been demonstrated that no vessel can be depended upon to hold it without loss above a temperature of 300° , so that nitrogen, which shows no irregularities up to 1600° , has been very generally substituted for hydrogen at the higher temperatures. The bulb is probably the most important single element in a constant-volume gas thermometer, and the progress of gas thermometry during nearly a hundred years has been closely associated with and dependent upon improvements in the bulb. The first bulbs were made of metal; Prinsep used a gold bulb in 1827; and their abandonment for porcelain in 1857 (Deville and Troost) is considered now to have been a step backward which was not retrieved for forty years.

Metal.	Point.	Atmosphere.	Crucible.	Temperature.	Reichsanstalt Scale.
Cadmium .	Melting and freezing	Air	Graphite	320.0 ± 0.3	321.7
Zinc .	Do.	Do.	Do.	418.2 ± 0.3	419.0
Antimony .	Do.	Carbon mon-oxide	Do.	629.2 ± 0.5	630.6
Aluminium .	Freezing	Do.	Do.	658.0 ± 0.6	657.0
Silver .	Melting and freezing	Do.	Do.	960.0 ± 0.7	961.5
Gold .	Do.	Do.	Do.	1062.4 ± 0.8	1064.0
Copper .	Do.	Do.	Do.	1082.6 ± 0.8	1084.1
Nickel .	Do.	Hydrogen and nitrogen	Magnesia	1452.3 ± 2.0	...
Cobalt .	Do.	Do.	Do.	1489.8 ± 2.0	...
Palladium .	Do.	Air	Do.	1549.2 ± 2.0	1575.2
Platinum .	Melting	Do.	...	1755.0 ± 5.0	...

The bulbs in use at the Reichsanstahl up to 1897 were still of porcelain, as were those used by Barus.

Porcelain is not an ideal substance for the bulbs, because it cannot hold the expanding gas without absorbing or losing some of it, and also because it is not absolutely uniform in its own expansion and contraction. Bulbs of platinum containing 10 to 20 per cent. of iridium for additional stiffness were used at the Reichsanstahl in 1900 for temperatures as high as 1200° C. and one of pure iridium was used up to 1600° C. in 1907. These bulbs are still in use. The Geophysical Laboratory used a 10 per cent. platinum-iridium alloy, but abandoned it for platinum containing 20 per cent. of rhodium. All these metal bulbs can be used up to 1600° C. with nitrogen without appreciable error in the return to 0° C. Pure silica bulbs have recently been used. Improvements have been made in the method of heating the bulb, chiefly by the substitution of electricity for gas as a source of heat and by enclosing the bulb in an air-

* *Metallurgical and Chemical Engineering*, May 1910, vol. viii. pp. 257-260.

tight bomb so that the pressure outside the bulb could be controlled and kept equal to the pressure inside. For still greater uniformity of heating some form of liquid bath will require to be devised for use at high temperatures. The table on previous page gives the melting-points of some metals obtained by Day and Sosman; the standard melting-points published by the Reichsanstalt in 1900 and now in general use are included for comparison.

The question of the accuracy of existing standards of temperature is discussed and the following estimate of accuracy is offered within certain temperature intervals:—

0° – 100°	$\pm 0.002^\circ$
100° – 300°	$\pm 0.05^\circ$
300° – 1100°	$\pm 0.8^\circ$
1100° – 1550°	$\pm 2.0^\circ$
1550° – 1750°	$\pm 5.0^\circ$

New Radiation Pyrometer.—A new form of radiation pyrometer is described by C. E. Foster* in a paper read before the American Electrochemical Society, May 1910. This instrument is of the fixed focus type, and consists of a tube at the front end of which is a diaphragm and at the opposite end is a concave mirror. The radiant heat from any hot body enters the opening in the diaphragm and a fixed proportion of it strikes the mirror. It is then collected at a certain focus where is placed a suitable thermo-couple. The calibration of the indicator scale is based upon the Stefan-Boltzmann law. Two standard scales up to 2400° F. and 3200° F. respectively are being made. The instrument does not require accurate levelling in use, nor is any clamping or other manipulation necessary.

* *Metallurgical and Chemical Engineering*, June 1910, vol. viii. pp. 345-346.

S T A T I S T I C S.

Mineral Production of Spain.—Of non-ferrous minerals produced in Spain during 1908 there were as follows :*—

	Tons.
Antimony	100
Arsenical pyrites	5,533
Quicksilver ores	42,210
Sulphur	13,872
Bismuth ores	96
Zinc ores	156,233
Copper ores	2,985,779
Tin ores	838
Platinum ores	441
Lead ores	126,676
Argentiferous lead ores	165,382
Tungsten ores	226

Metallurgical Production.—From the foregoing ores there were produced :—

Mercury	1,067,588 kilogrammes
Granulated zinc	6,357 tons
Sheet zinc	2,693 „
Crude copper	19,598 „
Blister copper	14,568 „
Platinum	129,881 kilogrammes
Lead	134,321 tons
Silver lead	53,741 „

Nickel in Canada.—During the year 1909 the production of nickel in Canada totalled 13,000 tons. The value of the metal produced during the month of October 1910 was £200,000.

* *Revista Minera*, vol. lxi. pp. 3-4.

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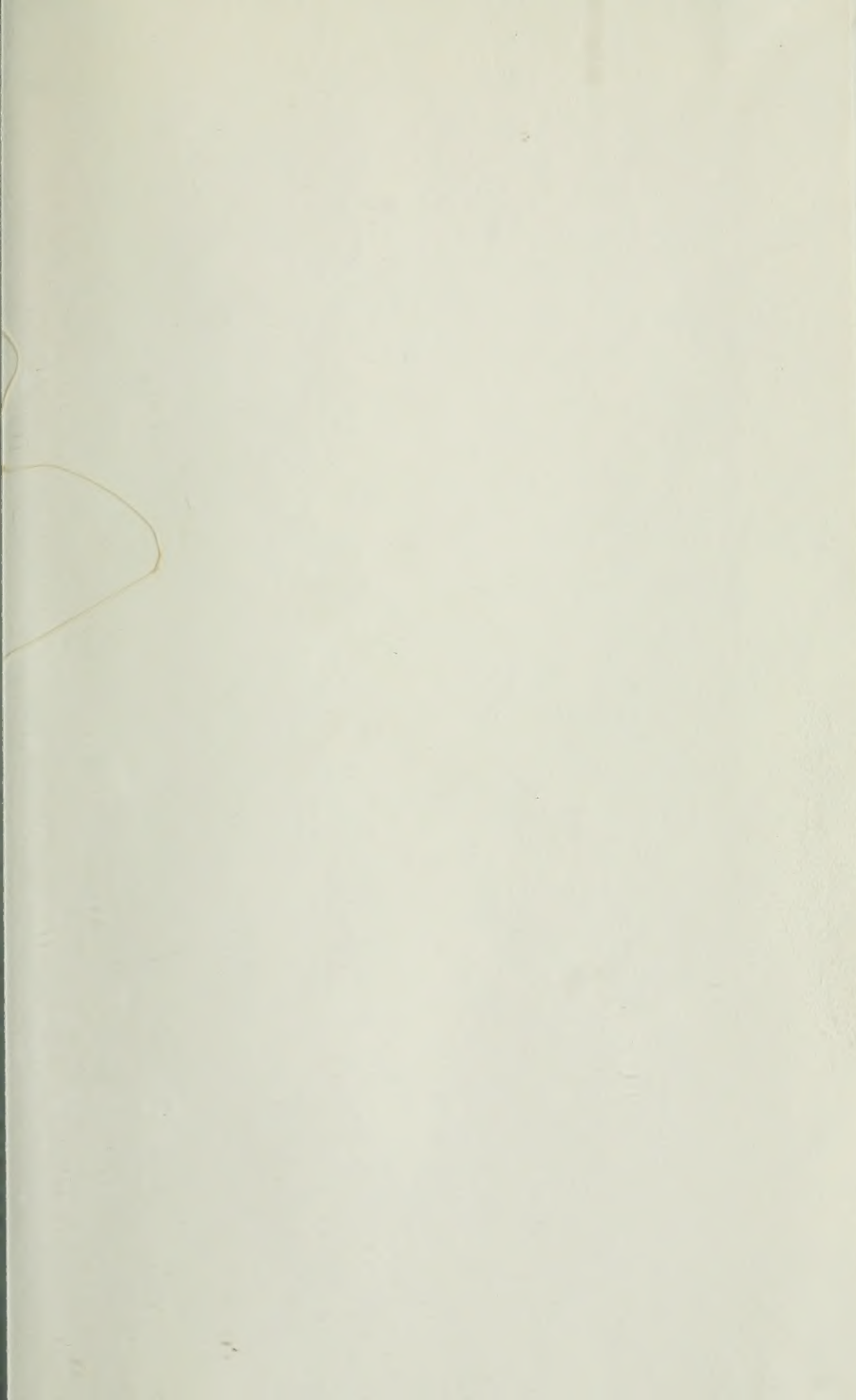
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